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ABSTRACT

This is the second of two volumes of source documents commissioned by the National Science Foundation in preparing the second 5-Year Outlook on Science and Technology for transmission to the Congress. This volume consists of the views of individuals selected by the Committee on Science, Engineering and Public Policy of the American Association for the Advancement of Science (AAAS) and the Social Science Research Council (SSRC) and 11 Federal agency reports. The papers written for the AAAS committee deal with public policy problems associated with science and technology. Those written for SSRC focus on current developments in social and behavioral science disciplines. The federal agency papers deal with anticipated problems, opportunities and constraints related to science, technology, and public policy from the perspectives of the missions of these agencies. Also included is a selected, annotated bibliography of published sources and a subject index to the two Source Volumes. (Author/SLH)

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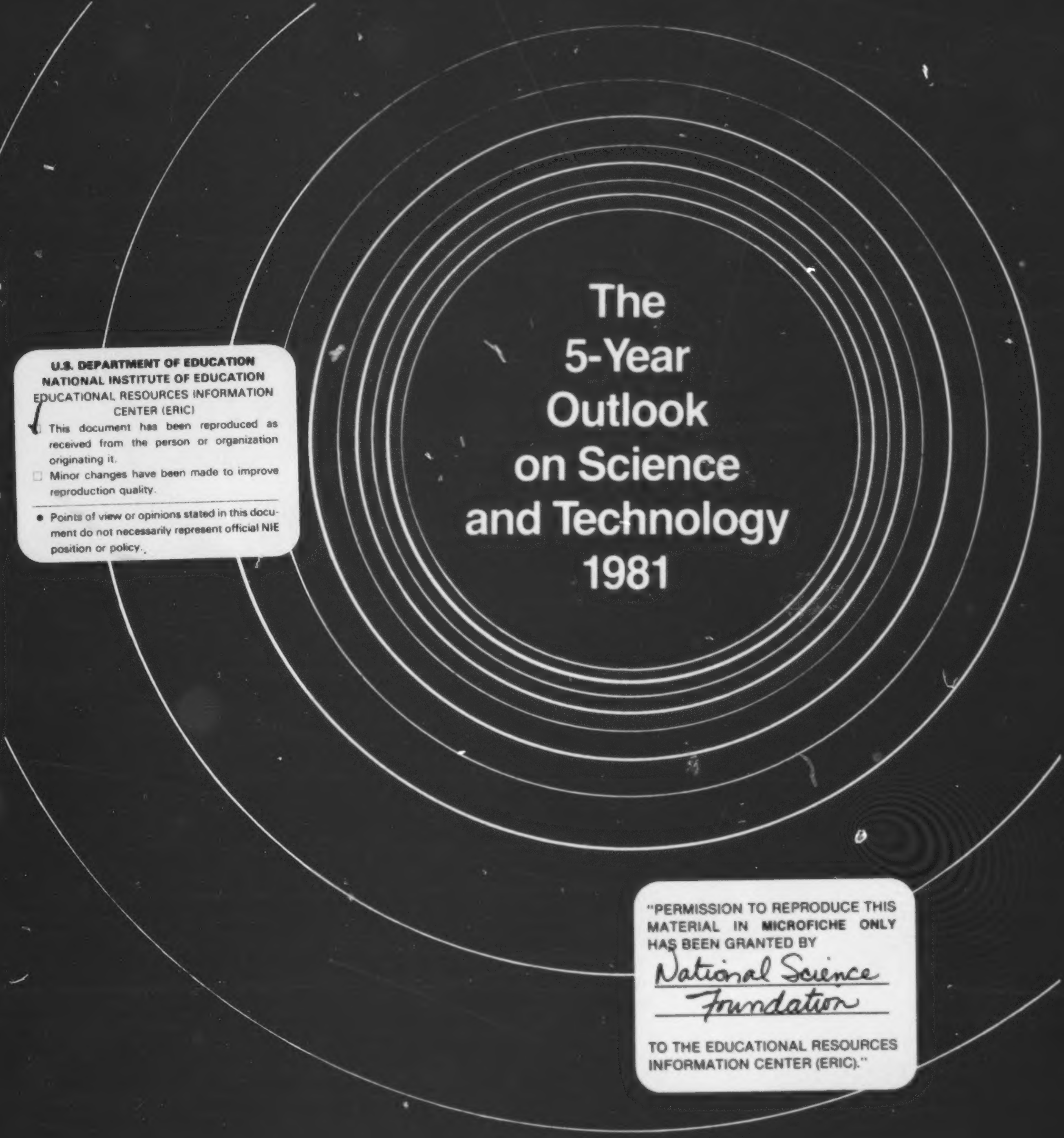

The 5-Year Outlook on Science and Technology 1981

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Source Materials
Volume 2

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2

Contents

Sources—Volume II

POLICY OUTLOOK: SCIENCE, TECHNOLOGY AND THE ISSUES OF THE EIGHTIES

A Report from the
American Association for the
Advancement of Science

PREFACE 389
Ray Thornton, Albert H. Teich

OBSERVATIONS: RACING THE TIME CONSTANTS 393
William D. Carey

I APPLYING SCIENCE AND TECHNOLOGY TO PUBLIC PURPOSES

1 APPLYING SCIENCE AND TECHNOLOGY TO PUBLIC PURPOSES: A SYNTHESIS 397
Richard A. Rettig

Introduction 397
Encouraging Scientific and Technological Innovation 398
Managing the Effects of Innovation 401
Securing a Livable World 402
The Challenge to Values and Institutions 404
Notes and References 406

2 THE INSTITUTIONAL CLIMATE FOR INNOVATION IN INDUSTRY: THE ROLE OF MANAGEMENT ATTITUDES AND PRACTICES 407
William J. Abernathy and Richard S. Rosenbloom

Introduction 407
American Management and Economic Decline 407
A Case in Point: Consumer Electronics 1955–1980 409
Managerial Attitudes and Practices 416
Conclusion 418
Notes and References 419

3 DECISION-MAKING WITH MODERN INFORMATION AND COMMUNICATIONS TECHNOLOGY: OPPORTUNITIES AND CONSTRAINTS 421
Donald J. Hillman

The Growth of Information and Communications Technology 421
The Rise of the Information Age 423
Policy Questions of the Information Age 424
Information Technology Forecasts 426
References 428

4 RELATIONS OF SCIENCE, GOVERNMENT AND INDUSTRY: THE CASE OF RECOMBINANT DNA 429
Charles Weiner

Introduction 429
Growth of DNA Research and Concern About Risks in the 1970s 430
Current Status of DNA Technology and Its Regulation 432
Applied Molecular Genetics in the 1980s: Policy Prospects and Problems ... 435
Conclusion 439
Notes and References 439
Bibliography 440

5 CHOOSING OUR PLEASURES AND OUR POISONS: RISK ASSESSMENT FOR THE 1980s 443
William W. Lowrance

Introduction 443
The Evolution of Mortal Afflictions 444
Improvements in Assessment 445
Institutional Attention 452
Scientific Integrity and Authority 454
New and Underattended Hazards 455
Recommendations 455
References 456

II SCIENCE, TECHNOLOGY, AND INTERNATIONAL SECURITY

6 SCIENCE, TECHNOLOGY, AND INTERNATIONAL SECURITY: A SYNTHESIS 461
Eugene B. Skolnikoff

- Introduction 461
- Background 461
- Key Issue Areas 462
- Institutions and Policy Process 471
- Conclusion 473
- Notes and References 473

7 UNITED STATES POLICY TOWARD SCIENTIFIC AND TECHNOLOGICAL DEVELOPMENT IN THE DEVELOPING COUNTRIES: THE CASE FOR MUTUAL BENEFIT 475
Charles Weiss, Jr.

- Introduction 475
- Science, Technology, and Foreign Policy Toward Developing Countries 476
- Current U.S. Policy and Programs 485
- Conclusions 488
- Notes and References 489

8 UNITED STATES AGRICULTURE IN THE CONTEXT OF THE WORLD FOOD SITUATION 491
Sylvan H. Wittwer

- Introduction and Background 491
- Reasons for the Shift to Biologically-Based Agriculture 493
- U.S. Agriculture and the World Food Situation 494
- The U.S. Agricultural Research System 494
- Food Production Research Priorities 496
- Biological Research and Food Production 496
- Human Resources for Agricultural Research 498
- International Agricultural Research Centers 498
- Conclusion 500
- Notes and References 500

9 TRENDS AND PROSPECTS IN WORLD POPULATION 503
Michael S. Teitelbaum

- Introduction 503
- Recent Population Trends 503
- Population Trends in Prospect 505
- Linking Population Trends to Other Problems 506
- Linking of Population Trends to International Security Issues 507
- Implications for U.S. Science and Technology 508
- The Outlook 509
- Notes and References 511

10 INTERNATIONAL SECURITY IMPLICATIONS OF MATERIALS AND ENERGY RESOURCE DEPLETION 513
William A. Vogely

- Introduction 513
- The Process of Resource Depletion 513
- The Concept of Resource Adequacy 515
- Worldwide Distribution of Reserves 517
- Resources and Economic Development 518

Role of Depletion 519
International Security Issues 519
Alternative Strategies 520
Summary 521
References 522

11 SCIENCE AND NATIONAL DEFENSE: A SPECULATIVE ESSAY AND DISCUSSION 523
Kenneth E. Boulding

Introduction 523
Science and National Defense 523
Summary of the Discussion 528
References 531

ACKNOWLEDGEMENTS

ADVISORY COMMITTEE 535
WORKSHOP PARTICIPANTS 537
MEMBERSHIP OF COMMITTEE ON SCIENCE, ENGINEERING, AND PUBLIC POLICY (COSEPP) 541

THE FIVE YEAR OUTLOOK FOR SCIENCE AND TECHNOLOGY: SOCIAL AND BEHAVIORAL SCIENCES

A Report from the Social Science Research Council

INTRODUCTION 545

1 ASSESSING THE SIGNIFICANCE OF SOCIAL SCIENCES RESEARCH ... 553
Kenneth Prewitt

Introduction 553
Six Principles of Social Significance 553
The Significance of Social Science: An Outlook 557
Reference 559

2 BEHAVIOR AND HEALTH 561
David S. Krantz, David C. Glass, Richard Contrada, and Neal E. Miller

Summary 561
Introduction 562
Behavioral Factors in the Etiology and the Pathogenesis of Physical Disease 564
Treatment and Rehabilitation of Physical Illness 575
Outlook for the Next Five Years 581
Note 585
References 585

3 ADVANCES IN METHODS FOR LARGE-SCALE SURVEYS AND EXPERIMENTS 589
Judith M. Tanur

Summary 589
Introduction 590
Total Survey Variability 592
Longitudinal Surveys 603
Social Experimentation 607
Uses of Administrative Records 611
And The Future? 613
Notes 614
References 615

4 THE LIFE-SPAN PERSPECTIVE IN SOCIAL SCIENCE RESEARCH 621
David L. Featherman

Summary 621
Introduction to the Life-Span Orientation 622
New Approaches in Research That Reflect a Life-Span Orientation 628
Public Policy and the Life-Span Approach 641
Note 644
References 644

5 STATISTICAL MEASUREMENT OF SOCIAL CHANGE 649
Albert J. Reiss, Jr.

Summary 649
Introduction 650
The Need to Measure Social Trends 650
Conceptual and Analytic Approaches 653
Priorities for Models and Measurement 658
Problems in the Development of a National System of Social Measurement . 662
A Five-Year Outlook for Research on Social Change 664
Note 665
References 666

6 SOCIAL AND EMOTIONAL DEVELOPMENT IN CHILDREN 669
Martin L. Hoffman

Summary 669
Introduction 670
Development in Infancy 672
Social-Cognitive Development 674
Moral Development, Aggression, and Prosocial Behavior: Influence of Parents, Peers, and Television 676
Motivation 680
Sex-Role Development 684
Effects of Maternal Employment 687
Impact of Divorce on Children 688
Future Directions 690
Notes 691
References 692

ACKNOWLEDGEMENTS 697

FEDERAL AGENCY PERSPECTIVES:

A Five-Year Outlook

INTRODUCTION 701

1 NATIONAL SECURITY 703

Highlights 703
Introduction 704
Electronics 704
Computer Technology: Artificial Intelligence, Automation, and Robotics 706
Command, Control, and Communication 707
Aeronautical Technology 708
Space Defense and Surveillance 709
Nuclear Test Verification 710
Weapons 710
New Materials Technologies 711
Human Resources 713
Health and Survival of Combat Forces 715

2 SPACE 717

Highlights 717
Introduction 717
Space Transportation and Operations 718
Origin and Evolution of the Universe 720
Sensing of Earth and Its Environment from Space 723
Communications and Data Management 724
International Cooperation 725

3 HEALTH 727

Highlights 727
Introduction 727
The New Technologies 728
National Health Problems 729
Other Scientific Opportunities 733
Technology Transfer and Assessment 733
Health Services Research 734
Notes and References 734

4 ENERGY 735

Highlights 735
Introduction 736
Fossil Energy Science and Technology 738
Nuclear Energy Science and Technology 743
Energy Conversion, Distribution, and Storage Systems 746
Solar and Other Renewable Energy Technologies 747
Energy End-Use Technology and Efficiency Improvement 749
Energy Research and Technology Base Support 750
References 752

8

5 GENERAL SCIENCE AND TECHNOLOGY 753
- Highlights 753
- Introduction 753
- Life Sciences 754
- Earth and Planetary Sciences 755
- Physical Sciences and Mathematics 756
- Engineering Sciences 757

6 NATURAL RESOURCES 761
- Highlights 761
- Introduction 762
- Tropical Forests 762
- Water Resources 763
- Arid Lands 763
- Remote Sensing of Natural Resources 764
- Natural Hazards 764
- Nonfuel Minerals 765
- Deep Ocean Minerals 765
- Marine Fishery Resources 765

7 ENVIRONMENT 767
- Highlights 767
- Introduction 767
- Solid Wastes 768
- Toxic Substances 769
- Energy and Environment 769
- Emergency Spills 770
- Hazardous Air Pollutants 770
- Gaseous and Particulate Air Pollution 771
- Nonionizing Radiation 771
- Pesticides 771
- Water Quality 772
- Drinking Water 772
- Climate 773

8 TRANSPORTATION 775
- Highlights 775
- Introduction 775
- Productivity 776
- World Trade 778
- Safety 779

9 AGRICULTURE 781
- Highlights 781
- Introduction 781
- Agricultural Production 782
- Human Nutrition 785
- Marketing and Postharvest Technology 787
- Structure of Agriculture and Policy Issues 787
- Rural and Community Development 789
- Reference 789

10 EDUCATION 791

- Highlights 791
- Introduction 792
- Research and Development in Education 792
- Education in Science and Engineering 795
- References 798

11 INTERNATIONAL AFFAIRS 799

- Highlights 799
- Introduction 799
- Science and Technology for Development 800
- Energy and Natural Resources 802
- Oceans and Polar Areas 804
- Environment and Health 804
- Information, Telecommunications, and Advanced Technology 806

APPENDICES

BIBLIOGRAPHY 811

- Maintenance and Development of the Science and Technology Base 811
- Contributions of Science and Technology to Industrial Innovation, Productivity, and Economic Growth 814
- The International Context of U.S. Science and Technology 817
- Science, Technology, and Policymaking 820
- National Security 822
- Space 824
- Health 826
- Energy 828
- Natural Resources 832
- Environment 835
- Transportation 837
- Agriculture 838
- Education 840

INDEX 843

POLICY OUTLOOK:

SCIENCE, TECHNOLOGY AND THE ISSUES OF THE EIGHTIES

A Report from the American Association for the Advancement of Science

The AAAS Board of Directors, in accordance with Association policy, has approved publication of this study as a contribution to the understanding of important policy issues. The interpretations and conclusions are those of the authors and contributors, however, and do not purport to represent the views of the Board or the Council of the Association.

Preface

Early in 1980 the National Science Foundation asked the American Association for the Advancement of Science (AAAS), through its Committee on Science, Engineering, and Public Policy (COSEPP), to provide it with assistance in the preparation of the second *Five Year Outlook for Science and Technology*. The *Outlook*, mandated by Congress in the National Science and Technology Policy, Organization and Priorities Act of 1976 (P.L. 94-282), is intended, in part, to identify and describe national problems in which scientific and technological considerations are of major significance and which warrant special attention by policymakers during the next five years. It is also intended to suggest opportunities for—and constraints on—using scientific and technological capabilities to contribute to the resolution of these problems and to achieve other national goals.

The AAAS Five Year Outlook Project was designed to address these public policy elements of the second *Outlook*. An *ad hoc* committee, constituted as a subcommittee of COSEPP, served as an advisory body to the project. A list of its members and the full COSEPP membership list appear in the Acknowledgements section.

The first task of the Advisory Committee was to identify the issues to be treated in the project. For this purpose, the Committee employed a compilation of potentially relevant issues and issue-clusters developed by AAAS staff on the basis of issues lists obtained from the Congressional Research Service, the House Committee on Science and Technology, the Office of Technology Assessment, the Office of Science and Technology Policy, and the AAAS itself, as well as other sources, such as the *New York Times Index*. The Committee reviewed the staff compilation and supplemented it with a number of its own suggestions. It then used a set of criteria developed by staff to evaluate the issues and select those that would be treated in the project. The criteria included:

- *importance of the issue to the national interest* (higher priority for issues with greater overall impact on the future of the nation and relation to closely-held values of the American people);
- *time-sensitivity* (not just immediacy, but concern for long-range consequences if no action is taken during the next five years);
- *involvement of science and technology* (centrality of their role in the issue and associated problems or in possible solutions);
- *breadth and relation to other issues* (definition in a manner sufficiently broad so that the papers could be reviewed and discussed jointly and so each would help illuminate the others);
- *adequacy of existing institutions to deal with the issue* (higher priority to issues for which existing institutional arrangements are inadequate);
- *contentiousness* (preference to issues around which there is substantial confusion or misunderstanding);
- *novelty* (less priority for issues which have received extensive attention recently, especially in the first *Outlook*).

The Advisory Committee identified two sets of issues, one set centering primarily on an international theme, the other on a domestic theme. For each of the issues, an individual with a solid command of both the academic literature and the policy environment was commissioned to prepare a paper defining the issue; describing what is known about it, including the best available projections of how the issue is likely to develop over the next several decades; and focusing on the policy implications for U.S. science and technology during the next five years.

In order to provide for a careful peer review of each of the papers, as well as to explore the inter-relations among the paper topics and to address the larger context within which the topics are embedded, AAAS convened two workshops, one organized around the international theme, "Towards Peaceful Change: Science, Technology, and International Security;" the other around the domestic theme, "Applying Science and Technology to Public Purposes."

The "International Security" workshop was held 11-13 November 1980 in St. Michaels, Maryland, and attended by 34 people. First drafts of five of the papers which appear in Part II of this report (Chapters 7-11) were presented at this workshop. The "Public Purposes" workshop was held 10-12 December 1980 in Hilton Head, South Carolina. Thirty-five people attended, and drafts of four of the papers from Part I of this volume (Chapters 2-5) were presented. Names of workshop participants may be found in the Acknowledgements section at the end of this report.

The participants at each workshop constituted a diverse group of experts in various aspects of science, technology, and public policy. Each participant was qualified to serve as a technical reviewer for at least one of the commissioned papers. Participants were selected to represent a range of policy perspectives, disciplines, backgrounds, and institutional affiliations. They were drawn from universities, government agencies, industrial firms, and non-profit organizations, and included demographers, computer and information scientists, geologists, economists, microbiologists, agronomists, and persons from a host of other fields.

Drafts of the papers were sent to the participants in advance of each workshop, and each brought to the workshop a written review of the paper closest to his or her area of special expertise. The first part of each workshop was devoted to intensive small group sessions in which the reviewers met with the paper authors to discuss their comments and to provide the authors with suggestions for revision. Subsequent workshop sessions, both small group and plenary, were devoted to exploration of interrelationships among the papers and to discussion of broader questions surrounding the paper topics.

In order to capture the outcome of the workshop deliberations, an additional paper—a "synthesis essay"—was commissioned for each workshop. The task assigned to the authors of these synthesis essays was to attend the workshop; to digest the key elements of the papers presented there, as well as the essence of the discussions that took place; and to prepare a paper that addressed the workshop theme and could serve in lieu of formal workshop proceedings. The synthesis essays were conceived as papers that, ideally, would be viewed by the authors of the workshop papers and by the workshop participants as incorporating and fairly representing their papers and deliberations. At the same time, the synthesis authors were expected to draw upon their own knowledge and expertise to provide overall structure, organization, and thematic unity that would go well beyond simple reportage.

Revised drafts of the papers presented at the workshops, plus drafts of the synthesis essays, were sent to participants for an additional round of review several weeks after each workshop. Reviews were also solicited from a variety of other individuals who had not attended the workshops. The final products, as presented in this report, have benefited from the reviews and workshop discussions. Nevertheless, it should be pointed out that they remain individual statements. No attempt was made to force consensus among the workshop participants, and many participants, no doubt, disagree with interpretations and policy positions contained in the papers. Similarly, the Advisory Committee and the AAAS, while seeking to assure that the papers and workshops were soundly based and of the highest quality, present them here in order to call attention to, and help illuminate discussion of, what they regard as vital issues—not to advocate particular points of view.

Numerous individuals contributed to this project and deserve credit for its accomplishments. We can only begin to list them. First we must note the central role of the Advisory Committee. Its distinguished members, whose names are listed at the end of this report, were extremely conscientious in fulfilling their responsibilities, contributed innumerable ideas, and provided thoughtful guidance throughout the course of the project. We are all deeply in their debt.

Most evident in this report, of course, are the contributions of the paper authors—both the authors of the original workshop papers and the authors of the synthesis essays. These capable and dedicated individuals labored under extremely tight deadlines, met them, subjected themselves and the products of their labors to intense scrutiny by groups of their peers, and cheerfully maintained both their equilibrium and a commitment to the project throughout. Less evident, perhaps, but no less important in the end, were the efforts of the workshop participants, who gave generously of their time and energy to review successive drafts of the papers, to discuss their reviews with the authors, and, in a sometimes difficult intellectual exercise, to search for the broader themes linking the papers to one another. All of these individuals, as well as the numerous outside reviewers who provided mail reviews of the papers, have our sincere gratitude.

Thanks are due also to William A. Blanpied and Alan Leshner of the NSF Office of Special Projects, and to William D. Carey, J. Thomas Ratchford, and William G. Wells, Jr., of the AAAS, all of whom had oversight responsibility for the project in one sense or another, for their support and guidance, as well as for helping to provide a strong sense of purpose and a commitment to quality in the overall enterprise.

Among those who, in one phase or another lent their hands, hearts, and minds to the project, and to whom we are grateful, are: Andrew Tolmach, summer intern at AAAS, who helped develop the list of candidate issues and selection criteria and helped define the paper topics; Ann Becker and Vicki Killian of Ann Becker and Associates, who guided the development and implementation of the workshop process; Carrie McKee, who edited the final manuscript; Joellen Fritsche and Marlene Povich, who helped design and typed the report; and Ginger Payne, who lent her secretarial and administrative skills to the project at several critical points. A special note of thanks must go to Jill Pace Weinberg, whose title of project secretary/administrative assistant barely begins to suggest the extent of her contributions.

We feel confident that we speak for all of these contributors and the many others from whose advice and assistance we benefited in expressing the sincere hope that this effort will bear fruit in improving our understanding of and ability to handle public policy issues involving science and technology.

Ray Thornton
Chairman, Advisory
Committee
Jonesboro, Arkansas

Albert H. Teich
Project Director
Washington, DC

Observations: Racing the Time Constants

*William D. Carey**

If we have learned anything at all about the uses of science and technology in the postwar years, it is that they have an unmistakable influence on contemporary trends and outcomes. They have helped to make the world smaller spatially, and larger numerically. They have multiplied our choices and scaled up our risks. They have put men into space and opened a new arena for warfare. They have illuminated man's beginnings and shaken age-old postulates about his worth and destiny. They have unlocked material abundance and laid new burdens on irreplaceable resources. They have expanded man's potential and dramatized his limits. They have advanced clarity and magnified uncertainty. They have penetrated the deepest reaches of knowledge and held a world hostage on the edge of crisis.

We have no reasons to suppose that science and technology will abate their influences upon trends and outcomes, and many reasons to expect that they will continue to shape society's choices and dilemmas. What is unprofitable is to try to outguess the rate of advancing knowledge and the forms and effects of its applications through technology. But it is a very different matter to recognize and array the emergent national and global issues confronting the United States and to explore with care the contributions that science and technology could make in managing such issues. What this report for the National Science Foundation seeks to do is to bring to the fore, for Congress and the concerned public, issues of high policy saliency where time is not on our side, and where the involvement of science and technology is large and growing.

Left to themselves and to a business-as-usual system of decision-making, science and technology will not extricate us from the trouble that is brewing. How science and technology are deployed, toward which goals, and at what rates of effort, all depend under our system upon the behavior and the quality of the nation's policy apparatus and, to be sure, on the public consensus that legitimizes decision-making. In each of the issue-areas with which this report deals, both time and information are central to deciding how the nation's policies are to be positioned and carried out. When lead time is wasted it cannot be recovered. If information is so shallow that policy routes cannot be laid out with confidence, inaction and confusion take the place of resolution. We cannot look to science and technology to dictate policy routes, but we require a broad and deep scientific and technological base upon which to construct and adapt our policy actions. The measure of that base is not represented by the money spent publicly and privately upon research and development, but in the appropriateness and the yield of these investments relative to the agenda of salient problems that we face. It is in this sense that policy for science and technology interbreeds with economic, domestic, national security, and foreign policies.

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*Executive Officer, AAAS

The eleven papers that compose the AAAS contribution to the *Five Year Outlook* do not begin to resemble a definitive catalog of the issues that will trouble American scientific, technological, and public policy over the next five years. But the papers *do* address representative issues of policy, and collectively they have the striking effect of revealing institutional gaps in our national policy machinery relative to dealing with the time constants that are present in varying degrees in the mix of issues.

It is possible to read the report from cover to cover, swimming through the troubled waters sketched by very competent authors, and finally put it down with a sense of an overwhelming agenda. It is possible also to pick and choose among the issues, arraying some in an eclectic structure of priority, although the AAAS itself has not presumed to rank them. But if the report as a whole has objective validity, it should drive us to ask whether our national policy machinery is up to the job of recognizing and dealing with the strategic choices that will be required to bring science and technology's weight to bear, effectively and in time, on the management of these issues. One's basis of confidence, on this score, is very low. The meanings of an exercise in projecting salient policy issues over a five-year period lie in questioning society's institutional capacities to formulate and manage multisectoral strategies aimed towards modifying or altering future outcomes of near-term issues. For a pluralistic society, the institutions favored by command economies are not available. Straight line policymaking does not fit our constitutional practice. A middle road, on which an informed political consensus is harnessed to decision-making, and is driven by a recognition of time constants, is the evident choice.

It might be objected that such counsels veer towards imagining the impossible. Yet, we are now witnessing something that not long ago would have seemed unimaginable, as the government's budgetary, monetary, regulatory, and tax strategies interact with the mechanisms of the market economy in designing and pursuing integrated goals for the nation's political economy. If rationalizing the nation's economic agenda is within our institutional capacity, other problems requiring rationalizing may not be out of reach. The lesson could well be that complex public issues, not excluding those involving the timely and effective uses of science and technology, are more likely to respond to coherent "process" management than to pretentious organizational inventions.

Such process innovations are not self-generating, especially in the case of issues that are not built as close to the ground as the state of the domestic economy. With few exceptions, the issues treated in this report are in differential stages of development and calibration. What they have in common, however, is the perceived time constant, which is one thing in the case of population growth and something else (highly uncertain) in the case of materials and energy resource depletion. The makeup of "process" management is not likely to be uniform in dealing with the horizon of issues that we have treated in these papers. From one issue to another, the process would call for different inputs of public policy, long-term corporate strategy, incentives and disincentives, collaborative R&D, and upgraded policy research including the social and economic sciences.

Spheres of responsibility will also look different from issue to issue, and it is not the thesis of this report that all responsibility converges on government and its institutions. *Some* responsibility does, however. The national interest is high across the whole array of issues, including those beyond the reach of the United States alone. Because none of the issues is unaffected by government's actions and failures of action, the very minimum responsibility of government is to organize itself in the best sense of "the national security" to keep lively surveillance over the development of issue areas, and to see to it that net assessments are made frequently and assimilated by the Congress and the planning arms of our national security and domestic policy machinery.

The residual concern that arises from a study of this kind is not trivial. It is that the problems are outpacing the quality and intensity of our responses, and by widening margins. The potentials of science and technology are not being pressed, much less strained, to meet the national interest. As the lead times shorten, driven by the time constants, risk and vulnerability increase. In the prophetic phrase of Thomas Wolfe, a wind is rising and the rivers flow.

I APPLYING SCIENCE AND TECHNOLOGY TO PUBLIC PURPOSES

1 Applying Science and Technology to Public Purposes: A Synthesis

*Richard A. Rettig**

INTRODUCTION

We live in an era of continuing scientific advance and technological change.[1] This statement, a truism since perhaps the sixteenth century, usefully orients us to the source of our present concerns. Not one but many scientific and technological revolutions go on around us every day; for example, revolutions in consumer electronics, information and communications technologies, and molecular biology—all of which are discussed in the papers in this volume. The scope and rate of change severely strain the capacity of existing economic, social, and political institutions to respond. "Whirl is king," as Aristophanes wrote, "having deposed Zeus."

Not surprisingly, the range and complexity of scientific and technological change are such that all contemporary societies, industrialized or developing, grapple with the effects of such change through their national governments. Few, if any, scientific and technological issues are of no concern to political leaders and institutions, and few, if any, political issues of moment lack scientific or technological importance.

Quite obviously, in the next five years, in the five years after that, and for the foreseeable future, the United States will confront a number of policy issues that derive in large measure from scientific or technological developments. These are policy issues, moreover, because they have penetrated the social, economic, and political fabric of our lives. They constitute an amalgam of accepted scientific and technological knowledge, scientific and technological uncertainty, and conflicting political and economic values. And they require collective action to manage if not resolve.

It might be assumed that nearly four decades after World War II, the historic watershed of government involvement with the scientific and technological establishments of this country, the management of the scientific-technological enterprise would have become second nature to us. The government's annual investment in research and development (R&D), for instance, has grown steadily from $1.2 billion in 1950 to $33.5 billion in fiscal 1980. In addition to direct federal expenditures for R&D, of course, the private sector of the economy invests comparable funds in R&D, an estimated $29.5 billion, for example, in 1980.

Indeed, there was a period in the early 1960s when optimism about the rate and direction of scientific and technological advance, confidence about our national capacity to manage such advance, and belief in the benign effects of the fruits of science and technology were at an all-time high. Since then, however, we as a nation have experienced great difficulties in managing the technological enterprise, especially in bringing science and technology to bear on economic productivity, comparative advantage in international trade, and innovation. We have also debated, vociferously at first but with increasing sophistication more recently, the undesirable effects of technological advance; indeed, the potential benefits of scientific advance have even been called into question. The optimism of the early 1960s yielded to pessimism in the late 1960s and early 1970s. Today, one hopes, the nation is moving beyond simple assumptions about the scientific-technological system to a more realistic view of its capabilities and limits and to a constructive recommitment to the use of science and technology for the common good.

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* Senior Social Scientist, the RAND Corporation, Washington, D.C. The views expressed in this paper are the author's and do not necessarily reflect the opinions or policies of the RAND Corporation.

The following four papers address in different ways certain of these policy issues. They do not do so exhaustively; rather, they focus selectively on critical aspects of these policy issues. The scope of these papers is limited mainly to the domestic United States, but not entirely so. Issues of international trade, the international nature of environmental pollution, and the international character of science itself, make it impossible to limit our attention exclusively to the problems of the domestic United States. Nor, as Eugene Skolnikoff's paper argues in the second part of this report, is it desirable to restrict it in that way.

Several major themes serve to organize this introductory overview essay. First, a policy issue of continuing high-level interest for the past decade is that of encouraging scientific and technological innovation. This issue knows no partisan sponsorship; only perhaps that matters of tone and emphasis may differ from one administration to another.

The second major theme is the need to cope on a continuing basis with the effects of the scientific and technological revolutions that are interlaced with our daily lives. Policy concerns begin with the aforementioned need to encourage innovations of this kind; they reach across all efforts to mitigate the adverse social, political, and economic effects of such advance.

Closely related to the second theme is the third, namely, the need to secure a livable world by managing the waste or effluent of an industrial society. The distinction between the two is that the latter is not primarily concerned with scientific and technological innovation as the immediate source of the problems of health, safety, and environment, but with all the sources of risk in the society.

Finally, an underlying theme of the papers, and the conference where they were discussed, is that scientific and technological advance has posed deep, perhaps unanswerable, challenges to our established political values, institutions, and processes. This last theme is perhaps the most disquieting because few have any clear vision about how to restore existing institutions to a satisfactory level of performance. But diagnosis must precede prescription, and recognition of the problem is thus a constructive step forward.

ENCOURAGING SCIENTIFIC AND TECHNOLOGICAL INNOVATION

The lagging productivity of the United States economy is a policy issue of great contemporary importance.[2] Growth in productivity increased at an average annual rate of 2.4 percent from 1948 to 1973, but from 1973 to 1978 it was estimated to have grown at less than one percent.[3] The 1981 report of the Council of Economic Advisers devoted considerable attention to this productivity decline, enumerating as causal factors the effects of government regulation, increases in energy prices, declines in the rate of growth of capital relative to labor, and decreases in spending on research and development.[4]

Edward Denison has suggested that the main source of decline is found in a set of determinants called "advances in knowledge."[5] This set includes technological knowledge—of physical properties and how to make, combine, and use physical things; as well as managerial knowledge—of business organization and management techniques in the broadest sense. Denison lumps the "advances of knowledge" determinants together with a set of miscellaneous ones (the effects of government taxation and regulation, the rise in energy prices, the shift away from manufacturing to services, and changing attitudes to work) in a "residual" category comprising those least easily measurable determinants of productivity. Commenting on what has happened since 1973, he says, "It is possible, even probable, that everything went wrong at once among the determinants that affect the residual series." In short, no single factor adequately explains the productivity decline.

In general, there exists a belief that declining R&D investments have contributed to declining productivity and that increased R&D spending has the potential for contributing to increased productivity. Considerable discussion exists about measuring these relationships, however, as well as about the appropriate policy instruments for influencing the situation. Some would respond by increasing federal funds for R&D; others favor changing the tax laws to encourage R&D expenditures by private firms.

The policy debate about the relations between research and development, innovation, and productivity will occupy an important place on the public agenda during the next five years. Policy remedies predictably will address themselves to the aggregate or macroeconomic level. In this volume, however, the paper by William Abernathy and Richard Rosenbloom stands in sharp contrast to this aggregate-level policy discussion, focusing in a provocative and instructive way on the issue of managerial knowledge among the leaders of American industry.

The point of departure for Abernathy and Rosenbloom is the decline of productivity and innovativeness of American industry. Noteworthy about their argument is that they are not primarily concerned with factors external to private firms that might be causing this decline, like inflation, high rates of taxation, and government regulation, factors that would increase the costs of production for U.S. firms relative to foreign competitors. Rather, they are troubled by the institutional climate for industrial innovation in American firms, by the attitudes and practices of American managers.

Abernathy and Rosenbloom argue that the attention of U.S. managers has been diverted from long-term technological change toward short-term adaptation to existing product markets. They observe that the analytic detachment that characterizes such managers is rooted in the financial (and sometimes legal) pathway to corporate leadership, detachment that contrasts with entrepreneurial leadership that derives from "hands on" experience with the R&D, new product, production, and marketing activities of the firm. Contemporary managers, they argue, display a preference for short-term cost-reduction rather than long-term technological investment. These managers are market-oriented, but in a particularly narrow way. They rely heavily upon market research and its ability to reveal consumer preferences, rather than depend upon the introduction of a new product to tap latent preferences and upon an educational campaign for altering those preferences.

Corporate growth and diversification, moreover, often result from the acquisition of companies not closely related to the firm's historic products. Rather, they are guided by the portfolio theory of financial risk management which results in a corporate strategy of spreading the risk among a number of diverse enterprises in a complex firm.

To illustrate the consequences of these changed attitudes and practices of American managers, Abernathy and Rosenbloom present a case study of the consumer electronics industry. Several features are noteworthy about this case. First, the consumer electronics industry, as Abernathy and Rosenbloom note, is not heavily regulated by the government, neither by traditional forms of economic regulation nor by more recent health, safety, and environmental regulation. Thus, the case forces a search for a different explanation of the loss of U.S. market position. Second, this high-technology product area was one in which U.S. firms, two decades ago, held dominant and undisputed leadership; so the case reflects a loss of market position that has resulted from head-to-head competition with the Japanese. Third, Japanese success lay in the ability of Japanese firms to foresee the application of a high-technology field—electronics—to a large consumer product market and a corporate willingness to pursue a strategy to develop that market. That strategy involved a long time-horizon for maturation of results, including a corollary willingness to make and learn from one's mistakes.

The argument is not entirely persuasive. The main hypothesis that the attitudes and practices of American corporate managers have contributed to the decline of U.S. international competitiveness is based on the single case of the consumer electronics industry. Thus, it cannot be automatically extended to even the entire electronics industry or to other industrial sectors. The validity of the argument undoubtedly varies across industries. Second, some will regard the case study data as more anecdotal than systematic in character.

Notwithstanding such criticisms, Abernathy and Rosenbloom have challenged the conventional wisdom on the central issue of declining productivity and the loss of the U.S. competitive international position. The important contribution of the paper, and of the Hayes and Abernathy paper that preceded it,[6] is that it points to the structural problem of managerial attitudes and practices as being a major factor contributing to the loss by U.S. firms of technological competitiveness. This issue needs to be widely debated, and nowhere more vigorously than in industry itself. The value of the paper has to be weighed as a contribution to the debate about causal mechanisms of and policy implications for the industrial productivity debate.

Scattered evidence exists that such a debate is beginning. A January 1981 *New York Times* story notes that "planning with more distant horizons has become a familiar theme among major American businesses, especially those competing in global markets where foreign competitors, particularly Japanese trading companies, have used the technique to achieve big gains in market share."[7] The account describes a shift in several U.S. firms to greater long-term strategic objectives; a grouping of enterprises within firms according to the appropriate, but differentiated, long-term objectives; and a linking of corporate salaries more directly to the fulfillment of long-term strategic objectives.

The Japanese themselves are participating in this debate. Recently, Akio Morita, who built the Sony Corporation into a worldwide success, pointed to several factors that give Japanese firms an advantage over U.S. firms.[8] These factors include: better long-term planning; bonus payments to employees rather than executives; and company-oriented rather than skill-centered executive careers.

A different manifestation of the debate, perhaps more directly supportive of Abernathy and Rosenbloom, is a recent *Harvard Business Review* article about the limits of "return-on-investment" (ROI) analytical techniques for the evaluation of the value of research to a corporation.[9] Mechlin and Berg argue that ROI techniques, when applied to research, fail to value research appropriately. Reasons include: (1) a temporal mismatch between the demands for immediate results and the "natural pace of innovation;" (2) the unpredictability of results of research and the inability of ROI to assess the value of negative results; and (3) the imprecision of measurement when the results of research may benefit many divisions of a company. The problems with ROI are exacerbated in cases where a central research organization exists for the entire corporation: intrafirm technology transfer is not adequately valued; nor is the effective use of slack resources of facilities and personnel; nor the overhead value of a consumer service function or a personnel recruitment agency. The authors urge supplementing ROI analyses with periodic reviews; mixed project selection, some by product managers and some by research laboratory personnel; calculation of ROI of research throughout a product's life cycle; observation of growth in the firm's relevant product line; and the analysis of ROI flowing from self-developed products. In short, the article urges sensitivity to the implications of financial analysis for the research investment and corrective actions that shift away from a short-term emphasis to longer time horizons. The debate appears to have begun.

What are the policy implications of the Abernathy and Rosenbloom argument? First, they address themselves to a problem rooted in the attitudes and practices of corporate managers and thus to an audience of American corporate leaders. Reform of the behaviors they criticize must come from corporate leaders, not from U.S. government officials. Refreshingly, in contrast to the instinctive tendency of many analysts and commentators, they do not turn to the federal government for help.

Second, U.S. firms, in concert with the U.S. government, may need to become more aggressive in seeking long-term international markets. In particular, Abernathy and Rosenbloom implicitly suggest the need for developing greater access to the Japanese domestic markets.

Third, two successive years of double-digit inflation remind us of the present economic context within which managerial behavior occurs. The 1981 report of the Council of Economic Advisers noted that inflation has risen from an underlying rate of about 1 percent in the first half of the 1960s to a present level of 9 or 10 percent. More ominously, the three major episodes of increase have each begun "with a sharp increase in the underlying rate and ended with the rate falling only part way to its original level."[10] So each successive inflationary period has started from a higher underlying rate than its predecessor.

This historical development of the underlying rate of inflation means that a very strenuous effort will be required to significantly decrease the underlying rate. Furthermore, as long as the rate remains high, American managers of whatever stripe will find few incentives to invest heavily in long-term R&D for the purpose of reestablishing technological leadership in particular industries and markets.[11] The need to control inflation is imperative.

Finally, concern for inflation relates closely to legislation to change the tax treatment of R&D. Such legislation, now being considered by Congress, would increase the incentives for investing in R&D with a long time to payoff. Public policies at this level could reinforce reform tendencies within American management in a constructive way.

Two issues are raised beyond immediate policy concerns by the Abernathy and Rosenbloom argument. In recent years, the educational requirement for corporate success has been the Masters of Business Administration (M.B.A.) degree. Implicitly, the authors (both professors at the Harvard Business School) are suggesting that the underpinnings of graduate business education need to be reevaluated. This implication deserves further articulation and discussion.

A second avenue of discussion opened by the paper pertains to the diffusion into the public sector of attitudes and practices similar to those deplored by Abernathy and Rosenbloom in the private sector. We may be witnessing a general weakening of commitment by the federal government and federal R&D managers to invest in long-term, high-risk, but potentially high-benefit scientific and engineering research. If this is occurring in parallel to a similar development within the private sector, then the long-term implications for the nation may be quite serious. Is there any evidence to suggest that such a development has been occurring?

Although evidence may be too strong a term, there certainly are signs that a long-term shift has been occurring in federal R&D management. Although the Mansfield amendment of 1969, restricting defense research to projects of direct military relevance, was on the statute books for only one year, many believe that it continues in force today.[12] Perhaps it is time to symbolically "repeal" this amendment by asserting that all federal R&D agencies have a responsibility to invest in R&D that is broadly appropriate to their mission, not just to that which is narrowly pertinent to specific operational capabilities.

The analog in the public sector of the ascendancy of financial and legal professionals to corporate leadership is the growing number of analysts—economists, M.B.A.s, and others—in the federal government. The general effect of such analysts on R&D is toward shortened time-horizons and sharper emphasis on payoff, a bias against long-term R&D investments.

Stronger pressures for payoffs from federal R&D have led in some instances to a misdirected concern for commercialization of R&D results. Better that the government should invest in building the scientific and technological foundations through long-term R&D than that it should try to pick commercial winners.

In university research, scientific equipment is becoming obsolete to an ever-increasing degree.[13] Moreover, academic researchers today devote a substantially larger portion of their time to administrative matters rather than to research. The effects of these trends can only be pernicious over time.

Three general points deserve statement in concluding this section. First, none of the above factors affecting federal R&D when taken alone is that consequential. It is the constellation of factors that is significant and the fact that they all move in the same direction. Second, the severity of the problem is not measured on a year to year basis, since this year looks very similar to last. But over five or ten years we see not continuity but discontinuity, a movement away from a commitment to long-term public R&D investments.

Finally, we may be losing sight of the rationale for supporting public R&D. The rationale is that public investment is needed because of an inherent tendency of private firms to underinvest in the generation of the external benefits of R&D, especially at the research and foundation technology end of the spectrum.[14] At a time when private R&D investments are increasingly constrained to short-term payoff projects, it would be quite unwise for public R&D to offer nothing but a mirror-image of that phenomenon.

MANAGING THE EFFECTS OF INNOVATION

Although the need to encourage scientific and technological innovation in the U.S. economy is keenly felt, it is also the case that several scientific and technological revolutions are currently going on before our eyes. One area of continuing scientific and technological innovation, now a quarter of a century old, is that of information and communications technology. Another, far less developed at present in its applications, but prospectively no less sweeping in its potential impact on medicine, agriculture, and industry, is that of molecular biology.

Donald Hillman, in "Decision-Making with Modern Information and Communications Technology: Opportunities and Constraints," correctly observes that our society is on the threshold of an Information Age. He provides an overview of the technical change occurring in the technologies of information and communications. This change, driven by the continuing evolution in solid-state electronics, is difficult to comprehend because of its rapid rate, the merging of the two technologies of information processing and communications, and because its manifestations are so widespread and pervasive throughout all aspects of daily life. The office, the factory, the commercial establishment, and even the home are being changed by this revolution.

Numerous major policy problems are raised by the impact of the information and communications revolution. The structure of the telecommunications and information industries is being reshaped; the question of individual privacy becomes more pressing; the management of resource data banks requires attention; as does the availability of international telecommunications and information resources. The formulation of public policy under such circumstances is an exceedingly difficult endeavor. Technical changes reducing costs and extending performance impinge forcefully on so many diverse policy areas, testing existing institutional and legal arrangements in each, that it is difficult to imagine coordination at the federal government level either by Congress, the Executive Branch, or the independent regulatory agencies. Furthermore, the application of change is so decentralized, so pervasive, that federal policy formulation is complicated by this fact as well. The challenge in policy terms is to deal sequentially and incrementally with each new policy issue in ways that balance a concern for reaping the benefits of technical change, mitigating its adverse effects, and establishing a flexible framework within which the intelligent guidance of change can occur.

Charles Weiner writes about another revolution, the emergence from sustained research in molecular biology of the gene splicing techniques of recombinant DNA. These techniques are now used to synthesize insulin, interferon, and other proteins such as industrially important enzymes, and also open the possibility of producing nitrogen-fixing feed grains. Strong scientific advance in molecular biology has been underway for several decades; the revolutionary applications of this body of scientific research are only now beginning.

Yet the recombinant DNA research is stamped indelibly in political and scientific minds as a threshold case in the relations of science to society. Whether this will appear true a decade hence, of course, is not clear. But the case represents what Nelkin has described as the renegotiation of the bargain between science and the polity, the bargain being unquestioning public support for science in exchange for a stream of beneficial science-based innovations.[15]

Why recombinant DNA is regarded as a threshold case warrants comment. First, the prospective benefits are potentially so diverse, so significant, and theoretically so reachable. From medicine to agriculture to industrial processes to environmental quality controls, a range of benefits are within grasp because of the relatively simple, elegant techniques of recombinant DNA.

Second, the potential benefits have been seen since the mid-1970s against a background of apprehension about the risks of recombinant DNA research. Weiner traces the concern for risk from the 1974 request by a group of prominent molecular biologists to their fellow scientists asking them to refrain voluntarily from performing certain experiments, to the 1975 Asilomar conference, the Cambridge, Massachusetts City Council debate about local restrictions on research at Harvard and the Massachusetts Institute of Technology, to the Guidelines for Research Involving Recombinant DNA Molecules, promulgated by the National Institutes of Health (NIH).

The NIH guidelines, Weiner notes, have been revised on three successive occasions since first being issued in 1976, each time becoming less restrictive. During the peak of public concern, legislation was proposed to extend the guidelines to industrial laboratories; that legislation was not enacted nor is it likely to be. Among most academic, government, and industrial scientists, a consensus exists today that the prospects of risky outcomes from recombinant DNA research have been steadily reduced, if not ruled out entirely. It is this proved reduction in risk, they argue, that justifies the relaxation of NIH guidelines and explains why restrictive legislation was not enacted. As Weiner notes, however, a few scientists and members of the public continue to express a residual concern for risk.

The third reason why the techniques of recombinant DNA are held in awe by so many thoughtful individuals is that they permit laboratory scientists to manipulate the very constituents of human life itself. Whether one believes that man is the product of a long evolutionary process—"thrown up between ice ages by the same forces that rust iron and ripen corn," to use Carl Becker's felicitous phrase—or the foremost expression of divine creation, the prospect of a few sequestered scientists seeking to "improve" the situation is sufficiently breathtaking to give us all pause. This concern, well founded or not, is sufficiently genuine to be in itself a counsel of prudence from society to the scientific community. Many bench scientists dispute the validity of this awe about manipulating the elements of human life, but that it influences public attitudes is incontrovertible.

The fourth, and more immediate, concern raised by recombinant DNA research is the challenge posed by rapid scientific advance to the social institutions of our time. In particular, what threats are posed to the integrity of the university, to open communication among scientists, to a heretofore largely self-regulated scientific community by the revolution in molecular biology?

Several common concerns underlie these two papers by Hillman and Weiner. First, the phenomenon of interest in each case is that of a powerful scientific and technological revolution. One case, the merging of information and communications technologies, represents a maturing effort whose effects are being felt across an incredibly wide array of applications. The case of molecular biology, and mainly the use of the techniques of recombinant DNA, is less developed; but we are on the threshold, in all likelihood, of several decades of far-reaching applications. In a fundamental way, moreover, each case is an instance of science-based technological change. The empirical or craft tradition in technological change will undoubtedly remain important in the years ahead, but the truly revolutionary technological change of the future will very likely be based upon major scientific advance.

Second, we value such scientific and technological change for the power it displays in several different dimensions. Rapidly declining costs characterize solid-state electronics and are likely to typify the applications of recombinant DNA techniques. Greatly increasing capability is a corollary characteristic. Breadth and diversity of application are yet other dimensions of change. The power of this technological advance is clear to all.

Third, this valued scientific and technological advance, encouraged by various government policies, must nevertheless be regulated. There no longer exists an easy one-to-one correspondence in belief that automatically equates scientific and technological advance with social, economic, and political progress. In the 1980s, our national commitment to scientific and technological advance is tempered by the realization that adverse consequences can result from the applications of such advance. This sober view is not antithetical to science or technology in inspiration, but neither is it uncritically accepting of a belief that science and technology produce unalloyed social beneficence. Perhaps our current situation is more than a mood, more than mere animus; perhaps it bespeaks of a deeper understanding of the relations between science, technology, and society.

SECURING A LIVABLE WORLD

During the 1970s, the regulatory reach of the federal government was greatly extended to new areas of economic and social life, especially for the purpose of reducing health, safety, and environmental risks. The signal of wide public support for this development was Earth Day, on 22 April 1970. The signal of institutional development was the creation of the Environmental Protection Agency in late 1970; other new agencies included the Occupational Safety and Health Administration (and the National Institute of Occupational Safety and Health), and the Consumer Product Safety Commission. Risk assessment emerged as the central analytical enterprise of this new regulatory activity, informing both the development of general policy and decision-making about particular cases in dispute.[16]

Several things can be said about this emergence of risk assessment. First, policy formulation and decision-making in health, safety, and environmental regulation have been permanently altered, and risk assessors have gained a place at the policy table.[17] Second, this alteration in the mix of participants in the policy arena has been facilitated, even required in some instances, by a strong trend to centralize policy control in the federal government. Centralization has had two dimensions: (1) decisions previously made by the private sector are now made jointly by the private and public sectors; and (2) policies once left to the states have now become the responsibility of the federal government. Third, though risk assessors are now policy participants, their assessments do not dominate policy formulation; most, if not all, assessments are not conclusive and reveal unresolved issues of scientific and technical uncertainty; and political decisions about the acceptable and desirable distribution of risks, costs, and benefits are required.

In this context, William Lowrance succinctly argues that the problems created for industry and government by risk-reduction regulation "stem as much from problems of societal attitude and decision-making procedure as from deficiencies of technical analysis and performance." He then suggests several heuristic steps to improve risk assessment and increase the likelihood that sound public policy will be articulated.

Rather than evaluate Lowrance's argument here, we can first clarify the social and political context in which it is written by asking several questions: What is the relationship between risk assessment and science and technology? How does risk assessment go beyond the concerns of science and technology? What is the nature of the political problem confronting risk assessment?

There are a number of diverse ties between risk assessment and science and technology. In the first place, certain areas of science are directly concerned with the physical phenomena that constitute the focus of much risk assessment. Broadly speaking, the environmental sciences have been differentiated from the other natural sciences in the past two decades, though the relationship to the earth sciences is often very close. Analyses of ecosystem behavior—a watershed, an air basin, a forest, for example—may be undertaken for scientific or regulatory reasons—or both. And a larger number of scientists in academic institutions are engaged in the environmental sciences today than was ever true before.

Second, certain areas of science have received strong impetus for development from the effort to regulate risks in health, safety, and environment. This is apparent, for example, in toxicology where substantial increases in research have occurred in government, academic and industrial research laboratories as a result of efforts to regulate the toxic effects of chemicals. It may be the case, however, that toxicological research has been devoted more to routine testing than to explicating underlying mechanisms of action.

Third, advances in instrumentation and analytical techniques have vastly extended the ability of man to detect and measure extremely low concentrations of pollutants in air, water, and food.[18] These advances in physical measurement have, quite often, reinforced demands for more regulation. Closely related have been technological advances in control technology. Indeed, a new and significant high technology industry has arisen in response to health, safety, and environmental regulation. This industry represents but another tie of risk assessment to science and technology.

Finally, certain industries have been implicated as bearing greater responsibility than others for worker safety and environmental quality. The chemical industry is one of the foremost among these, being the object of risk assessment concerns for worker safety in handling dangerous materials, consumer product safety for products like asbestos insulation, and environmental quality that is affected by direct, widespread introduction of a dangerous chemical substance like PCBs (polychlorinated biphenyls). An industry so dependent upon science in the first instance necessarily requires highly trained, scientific risk assessors.

It is important to observe, however, that risk assessment goes beyond science and technology and embraces a larger set of issues. Risk assessment, and the regulatory regimes in which it is applied, typically concerns the byproducts—the effluent—of modern industrial society whether generated by individuals, private firms, or governments, at every stage from extraction to production to distribution and use of the primary products. The immediate products of science and technology may be included in the domain of risk assessment, but the reach of that domain is far larger.

As a result of the scope of the risk assessment domain, risk assessors are drawn from widely diverse intellectual fields—physical and natural sciences, engineering, operations research, systems analysis, economics, social science, law, and medicine. They are affiliated with a range of different institutions—universities, research and analytical institutes (both nonprofit and for-profit), private industrial firms, government regulatory agencies (at all levels of government), and public interest law firms. Not surprisingly, therefore, competing and conflicting values, preferences, and biases inform the assessment effort regardless of the agreement that may exist on analytical techniques.

In this context, however, analytical techniques can provide powerful assistance to policy formulation. The nature and scope of the particular risk can be clarified, mechanisms of exposure identified, prospective remedies considered, and their respective costs and benefits assessed. But two factors limit the utility of risk assessment. First, though many assessments may identify some critical uncertainties associated with the mechanisms or effects of the risk or its remedy, they often are unable to reduce those uncertainties to an insignificant level by analytical or scientific means. And second, conflicts that arise from the inability of risk assessment to develop a comprehensive description of a risky situation and to specify causal relations between insult, effect, and remedy, can only be resolved by policy officials acting politically—that is, exercising authoritative discretionary judgment about the preferred allocation of risks, costs, and benefits for any given situation or class of situations.

Lowrance would improve the process of risk assessment for the purpose of focusing conflict on essential issues and facilitating the political resolution of such conflict. The greater use of comparative analysis, the explicit statement of standards of risk, the specification of risk-management goals, weighing risks in relation to costs and benefits, are all means to this end. He also suggests that we move with alacrity to identify, first, the cases of "negligible risk" and dismiss them, and—at the other pole—the cases of "intolerable risk" and cease creating them. Between these two poles, Lowrance urges that we set priorities for allocating the scarce resources needed to conduct risk assessments.

An interesting contrast is suggested, however, between Lowrance's recommended strategy and Weiner's account of the recombinant DNA "risk assessment" exercise. The former is rightly concerned about how risk assessment can facilitate the development of political consensus in the resolution of health, safety, and environmental controversies. Yet he addresses himself mainly to improving the analytical aspects of risk assessment.

Weiner, on the other hand, reports on a process initiated by concerned scientists that involves a complex dialogue between scientists and the general public. That dialogue has taken place on university campuses, in city councils, Congressional committee hearings, and in the NIH Recombinant DNA Research Advisory Committee. The implicit lesson is that concerns for risk have been allayed in large measure because of scientific developments, but also because the process has forced the scientific community into sustained communication with the public.

It is important to juxtapose the analytical and process features of risk assessment. Analysis is essential, but cannot provide the "right" answers. And, because value conflict is likely for any specific risk-reduction effort or policy, procedures that encourage the development of political consensus are also essential to the formulation of sound public policy.

The prospects for achieving political consensus about risk assessment in the 1980s, however, may be fragile. The decade of the 1970s, as noted earlier, witnessed great extension of federal regulatory activity in health, safety, and environment. By the end of the decade, there was a growing body of opinion that this regulatory impulse had been carried too far and that its excesses needed to be trimmed back. One expectation about the 1980s, therefore, was that rationalization of the new regulatory area might be undertaken, that is, recognition of the merit of the concern for risk, acknowledgement of the excesses of the consequent regulatory burden, and a balancing of the competing values in conflict. Subsequent to January 1981, however, and the advent of a new administration, the prospect exists of a far-reaching effort to undo much of the work of the 1970s, not only the excesses and undesirable burdens but the meritorious effects as well. Whether the United States as a society is close to developing a political consensus about the role and purpose of risk assessment, and its attendant regulatory activity, will be revealed in the next few years. That is the essential question, however, since risk assessment is, in the last analysis, a political issue.

THE CHALLENGE TO VALUES AND INSTITUTIONS

Throughout the four papers there runs an undercurrent of anxiety about the adequacy of existing societal institutions and processes to deal with the diverse challenges raised by science and technology. This anxiety was even more pronounced in the conference discussions in December 1980 at which the papers were initially presented.

Reasons for this anxiety are suggested by the examples on every hand. Corporate managers of United States firms may in many instances be ill suited by training, career plans, and orientation to recognize the requirements for maintaining technological leadership. Information and communications technologies are altering the way we work and live and do business, stretching existing legal and institutional frameworks to their limits, yet these scientific and technological revolutions are still guided by increasingly obsolete policies. The commercialization of molecular biology is placing severe strains on many universities, both between faculty members and their institutions and among faculty members themselves. And the demands that give rise to risk assessment—for example, the control of the effects of acid rainfall or the guarantee of safe disposal of radioactive nuclear waste—test the society's capacity to devise solutions that are technically, economically, and politically satisfactory.

The challenge of science and technology goes to all societal institutions, from private corporations to universities to the legislative and executive councils of the public sector. A principal source of the challenge is the continuing impact of scientific and technological change which, as Skolnikoff puts it, has been central to "the restructuring of nations and of international affairs, particularly in the 35 years since the Second World War." Policy issues have become a complex amalgam of scientific, technological, economic, and political factors. Institutional relationships have also become more complex, largely an adaptive response to the impact of scientific and technological change. National and international spheres are more closely related than ever; public and private sector roles are as difficult to define; and society is increasingly organized into large institutions that share responsibility for governance, usually without commensurate authority. Continuing rapid and widespread scientific and technological change, increasing technical complexity, and overwhelming institutional complexity—these are the characteristics of the challenge to societal institutions raised by science and technology.

What is the precise nature of the problem posed by science and technology? It consists of three elements. First, the political institutions of popular, democratic control are inadequate to guide the scientific and technological enterprise and mediate its effects. Surprisingly, none of the authors looks to the election of public officials as providing expressions of voter preference on policy issues of any scientific or technological consequence. Nor do they look to elected officials in state legislatures or Congress for significant policy guidance, though that might be a reasonable expectation in a democratic society.

The authors, who come from backgrounds in physical science, engineering, applied social science, and history, and the scientists, engineers, businessmen, and analysts concerned with managing the scientific and technological enterprise, are oriented to the executive agencies of the federal government. Often, however, a great ambivalence exists toward established authority, and great concern exists about the adequate representation of "the public" in policymaking. It is clear that the "notice and comment" means of securing critical information from interested parties, technical experts, and the general public draws only tepid support from many in the scientific and technological communities. Nor does reliance upon the court system, either for fact finding or dispute settlement, engender any deep allegiance from the community of experts.

Nevertheless, the problem remains of how to appropriately consult the public on issues where scientific and technological considerations loom large. Is the public represented by articulate public interest groups, other parties at interest, or the citizenry at large? Is it to be consulted through the notice and comment procedures of administrative rule making, through public hearings, through formal advisory bodies, or how? The irony should not be lost. Having ignored elections and legislatures—the central institutions of public participation in the governance of our society—we then search seriously but with limited success for acceptable substitutes. The dilemma is one of the deeper institutional crises of our times and impinges directly on the issues raised by science and technology.

The second element of the problem is that elite opinion in the United States is deeply divided on the appropriate response to a number of key policy issues affecting the scientific and technological enterprise. Whether the issue is the cause of productivity decline, the effective means of stimulating innovation, the importance of maintaining a strong scientific and technological base, or the appropriate strategies for balancing health, safety, and environmental concerns against economic considerations, wide divergence of opinion exists among academic, industrial, and governmental leaders. The absence of elite consensus contrasts, for example, with the period just after 1957 when the United States responded to the Soviet Union's triumphant initial entry into outer space. Without such consensus, clear signals cannot be given to the scientific and technological enterprise and popular support for agreed-upon policies cannot be generated.

The final element of our present difficulty is that the scientific and technological establishment itself is left in a vulnerable position and one from which it is unable to exercise strong leadership. The inadequacy of the institutions of popular control to provide guidance to the enterprise is a recent problem and troubling in its own way. But deeply divergent views among elite policy opinion leaders are more unsettling.

Are there responses to this complex challenge posed by the relentless march of science and technology? At one level, it must be remembered, a number of thoughtful men and women grapple with the day-to-day manifestations of the full range of policy issues raised by and affecting science and technology. This daily hand-to-hand combat, so to speak, responds in an important way to the challenges the society faces.

Beyond the attention given to the immediate aspects of the challenge, however, it is necessary that the task of forging political consensus about major national strategies for science and technology receives high priority in all quarters of the interested public. The quality of dialogue that is required to reconcile the complexity of scientific and technological issues with the need for elite consensus and broad public support is high. Deepening and enriching that dialogue should be a matter of concern to all.

Finally, it may be the appropriate historical period to think more seriously about decentralized responses to the challenges of science and technology. Both the revolutions of information and communications technology and of molecular biology are awesome because their current or expected applications penetrate so deeply into so many facets of contemporary life. The capacity of centralized policy formulation by the federal government is taxed perhaps beyond its limits if it attempts to respond to the full scope and complexity of scientific and technological change. The recombinant DNA lesson may represent in an important way, then, an early model of how the scientific and technological communities and the public ought to engage each other as they mutually strive to guide the societal response to science and technology.

These challenges to values and institutions deserve serious, sustained attention by many in the years ahead because the effects of scientific and technological advance are sufficiently powerful to alter our lives and patterns of social, economic, and political organization. If change must come, better that it should be subjected to continuous scrutiny, discussion, and debate within the framework of democratic institutions rather than take us unawares.

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2 The Institutional Climate for Innovation in Industry: The Role of Management Attitudes and Practices

*William J. Abernathy * and Richard S. Rosenbloom ***

INTRODUCTION

Evidence of decline in the productivity and innovativeness of American industry is being interpreted in various ways as government, industry, and academia struggle to comprehend a troubling phenomenon. Some analyses point to such external factors as inflation, taxation, and regulation, which have the common effect of increasing costs incurred by U.S. firms in relation to their foreign competitors. Others stress institutional factors such as industry structure and the attitudes and practices of managers.

The institutional climate for innovation is important to the behavior of industry. By climate we do not mean just a set of factors external to the firm, but a set of attitudes and practices observable within business. Certain basic managerial assumptions shared widely within American culture shape competitive strategies. Strategy, in turn, provides the link between firm and environment.[1]

This paper examines a series of innovations in the consumer electronics industry to explore the strategic role of management attitudes and practices in the management of technology.[2] We hope that this case study of an industry will stimulate other empirical examinations of the consequences of prevalent American managerial precepts. The recent history of the consumer electronics industry provides a fertile ground for exploring broader issues. Of particular interest are the contrasts between the strategic behavior of certain Japanese competitors in that industry and the behavior of the leading American firms.[3] Analysis of these contrasts can lead to useful insights into fundamental problems facing American industry in the 1980s.

AMERICAN MANAGEMENT AND ECONOMIC DECLINE

Speculation during the Reagan presidential transition about the possible declaration of a National Economic Emergency dramatized widespread concern about the health of the American economy. Symptoms of fundamental economic difficulty have been emerging for at least a dozen years. These include increasing rates of inflation and unemployment, and declining balances of international trade in key industries.

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The causes of these basic problems are complex. The relative importance of contributing factors remains a matter of judgment and debate. There is little disagreement, however, that improved utilization of technology can be a vital part of any remedy. The "Stevenson-Wydler Technology Innovation Act of 1980" finds that:

> Industrial and technological innovation in the United States may be lagging when compared to historical patterns and other industrialized nations.[4]

Available indicators of national trends in technological innovation, although neither direct nor conclusive, do provide cause for concern. A recent summary of these trends, presented in an article by one of the present authors (Abernathy) with Robert H. Hayes,[5] points out that:

- labor productivity is increasing more slowly in the United States than in most other industrial nations (Table 1);
- rates of productivity growth through the U.S. private sector peaked in the mid-1960s (Table 2);
- expenditures in industrial research and development (R&D), as measured in constant dollars, also peaked then in absolute terms as well as in relation to Gross National Product (GNP) (Figures 1 and 2).

Although some have attributed these trends to economic or political factors, Hayes and Abernathy argue that the central explanation lies in the attitudes and practices of American managers. In their view, success in the world marketplace requires an organizational commitment to compete on technological grounds, by offering superior products or superior manufacturing processes.

Table 1—Growth in Labor Productivity Since 1960 (United States and Abroad)

	Average annual percent change	
	Manufacturing 1960–1978	All industries 1960–1976
United States	2.8%	1.7%
United Kingdom	2.9	2.2
Canada	4.0	2.1
Germany	5.4	4.2
France	5.5	4.3
Italy	5.9	4.9
Belgium	6.9*	—
Netherlands	6.9*	—
Sweden	5.2	—
Japan	8.2*	7.5

*1960–1977.

Source: Council on Wage and Price Stability, *Report on Productivity* (Washington, D.C.: Executive Office of the President, July 1979). Reprinted from Robert H. Hayes and William J. Abernathy, "Managing Our Way to Economic Decline," *Harvard Business Review*, vol. 58 (July-August 1980), p. 69.

Table 2—Growth of Labor Productivity by Sector, 1948–1978

	Growth of labor productivity (annual average percent)		
	1948–65	1965–73	1973–78
Private business	3.2%	2.3%	1.1%
Agriculture, forestry, and fisheries	5.5	5.3	2.9
Mining	4.2	2.0	−4.0
Construction	2.9	−2.2	−1.8
Manufacturing	3.1	2.4	1.7
Durable goods	2.8	1.9	1.2
Nondurable goods	3.4	3.2	2.4
Transportation	3.3	2.9	0.9
Communication	5.5	4.8	7.1
Electric, gas, and sanitary services	6.2	4.0	0.1
Trade	2.7	3.0	0.4
Wholesale	3.1	3.9	0.2
Retail	2.4	2.3	0.8
Finance, insurance, and real estate	1.0	−0.3	1.4
Services	1.5	1.9	0.5
Government enterprises	−0.8	0.9	−0.7

Note: Productivity data for services, construction, finance, insurance, and real estate are unpublished.

Source: Bureau of Labor Statistics. Reprinted from Robert H. Hayes and William J. Abernathy, "Managing Our Way to Economic Decline," *Harvard Business Review*, vol. 58 (July-August 1980), p. 69.

As interpreted in "Managing Our Way To Economic Decline," American managers, guided by what they believe are the newest and best techniques for management, have increasingly directed their attention to matters other than innovation. These techniques, despite their sophistication and widespread usefulness, seem to have encouraged analytic detachment at the expense of the insight that comes from "hands on" experience. They promote a preference for short-term cost reduction rather than long-term development of technological competitiveness. According to Hayes and Abernathy, by concentrating on serving existing markets rather than creating new ones, and by excessive emphasis on short-term financial returns and "management by the numbers, many firms seem to have decided against striving for long-term technological superiority as a competitive weapon. They may thus have made themselves vulnerable to competitors whose strategic thrust leads to technological superiority and market leadership.

This provocative thesis attracted widespread attention and acclaim, which the editors of the *Harvard Business Review* believe may have exceeded that of any article ever published in their frequently cited journal. The seven judges for the McKinsey Award, given annually to the best article in the *Review*, unanimously awarded it first prize in 1980.[6]

This thesis is elaborated and made concrete in the following case study of innovation in the consumer electronics industry, which emphasizes certain strategic choices made by Japanese and American firms competing in the U.S. market. While the study suggests certain

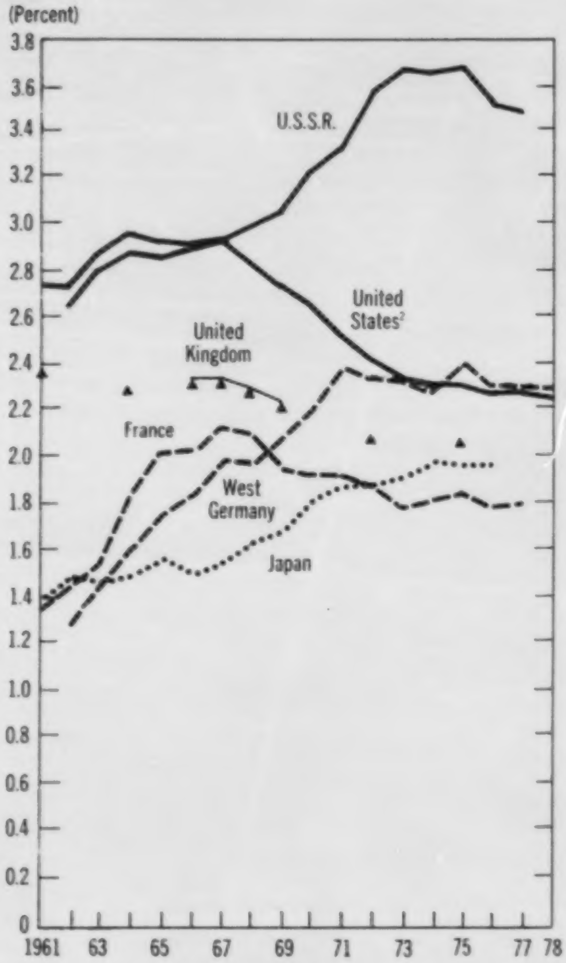

Figure 1. National Expenditures for Performance of R&D[1] as a Percent of GNP by Country, 1961–1978

[1] Gross expenditures for performance of R&D including associated capital expenditures.
[2] Detailed information on capital expenditures for R&D is not available for the United States. Estimates for the period 1972–1977 show that their inclusion would have an impact of less than one-tenth of 1% for each year.
Source: *Science Indicators—1978* (Washington, D.C.: National Science Foundation, 1979), p. 6.
Note: The latest data may be preliminary or estimates.

hypotheses and generalizations, it cannot, of course, "prove" their universality. Although we view this case as an interesting example of the strategic use of technology to gain market leadership, we do not imply that such a strategy is always appropriate.

A CASE IN POINT: CONSUMER ELECTRONICS 1955–1980

American firms pioneered in consumer electronics technology and until the 1960s took the largest share of revenues and profits in the world's markets.[7] In 1955, U.S. output in consumer electronics was $1.5 billion; Japanese firms produced a mere $70 million. Twenty-five years later the situation is reversed, with Japanese revenues in consumer electronics more than twice those of the U.S. manufacturers. And volume is not the only measure of Japanese leadership. Japanese designs usually offer the highest levels of performance. Unique features, such as the bilingual or stereo sound tracks, are available on television receivers in Japan. Japanese firms also have an overwhelming lead in the most exciting and lucrative new consumer product to reach the electronics

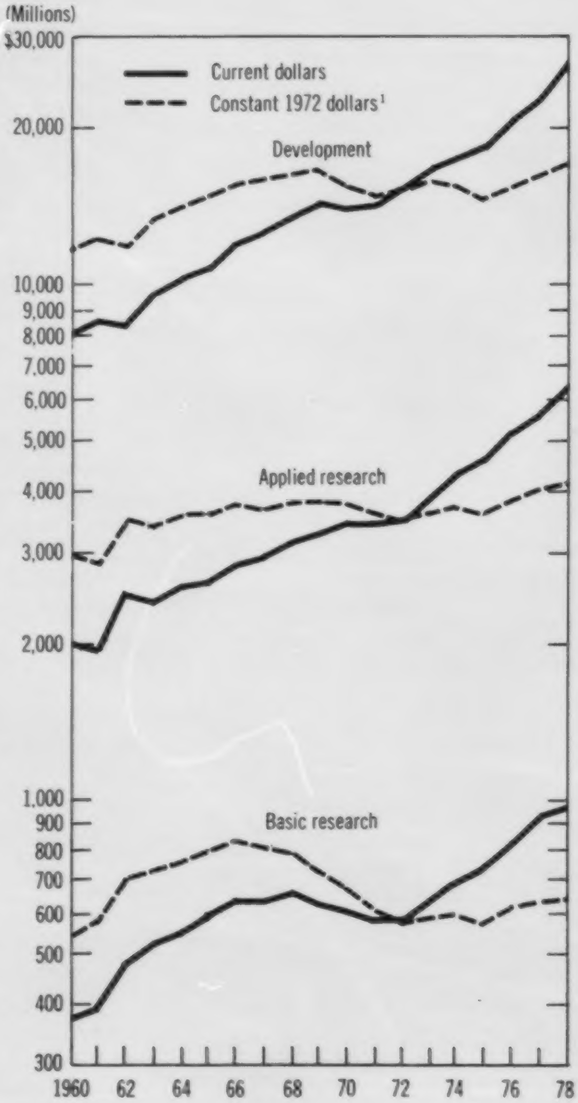

Figure 2. Industrial R&D Expenditures for Basic Research, Applied Research, and Development, 1960–1978

[1] GNP implicit price deflators used to convert current dollars to constant 1972 dollars.
Source: *Science Indicators—1978*, p. 87.
Note: Preliminary data are shown for 1977 and estimates for 1978.

industry since the heyday of color television in the mid-sixties: the videocassette recorder (VCR). Factory sales of VCRs, worldwide, exceeded $3 billion in 1980 and 95 percent of those revenues accrued to firms in Japan.

How did this startling reversal come about? More to the point, how did the "imitative" Japanese seize the innovative leadership in this large and important industry? Is this an isolated circumstance or is it the forerunner of more to come? Let us look at the history of the VCR and how a handful of Japanese companies came to dominate a major world market by tracing the history of the consumer electronics industry in the United States and Japan since 1955.

In the mid-1950s, consumer products represented only one-fourth of the output of the U.S. electronics industry; the balance consisted of industrial and military equipment. Yet, in absolute terms, consumer electronics was a big business, accounting for $1.5 billion in factory sales in 1955, the year of peak sales for monochrome television sets. Output of some eight million television sets, valued at one billion dollars, provided two-thirds of the entire consumer electronics industry's revenues that year. (The remainder came largely from radios and phonographs.) But the consumer market for television was by then nearly saturated (88 percent of all homes would have a set by 1960), and demand leveled off in the late 1950s at about six million sets per year—98 percent of them black and white. Most sets were either table or console models with screen sizes of about 20 inches measured diagonally. In a highly competitive market, manufacturers standardized their products to gain volume, efficiency, and hence a lower retail price to the consumer. A few manufacturers tried to introduce "portable" 19-inch models as second sets, but without much success. As a result, a shake-out among some 150 television set manufacturers left only 27 in 1960. It would be another five years before the industry experienced another boom with the growth of demand for color television.

The situation in Japan in the 1950s was quite different. Starting from a small base, the output of the Japanese consumer electronics industry increased tenfold from 1955 to 1960. Television set production amounted to only about $30 million in 1955, slightly less than the value of radios produced that year. But by 1960 television sets were already the dominant product in Japan's domestic market—59 percent of the consumer electronics output—and 45 percent of Japanese households had already acquired a television set.

Despite the booming demand for television at home, Japanese firms invested significantly between 1955 and 1960 in opening new markets for radio sets abroad. The story of their 1956 "invasion" of the U.S. radio market with all-transistor portables is well known.[8] Offering a line of miniature receivers half the size and weight of the smallest American products, Japanese producers, led by Sony, developed a major new market segment and met little American competition. Annual sales of portable radios in the United States grew by a factor of seven within a few years and Japanese imports captured two-thirds of the increase.

By 1960, then, export markets were already significant to the Japanese producers. Products valued at $150 million (87 percent of which were radios) were shipped abroad, representing 20 percent of the Japanese industry's output, while U.S. consumer electronics producers exported only $25 million worth, about 1 percent of their output. As a consequence, by 1960 the scale of consumer electronics production in Japan was already one-third that of the American industry and gaining fast.

The Japanese firms had not yet made inroads into the larger and potentially more profitable television receiver business in the United States, but they were now ready to try. Having achieved an economic scale of production, and possessing a large labor-cost advantage, a Japanese firm might well hope to enter the mainstream of the monochrome television mass market. Some tried in the second half of 1960 with 19-inch sets, but without much success; these sets, even at a low price, did not offer sufficient advantages over the established American brands. In 1961 the Japanese share of the U.S. market was a negligible 0.3 percent.

One Japanese firm, rather than competing with the U.S. firms in their areas of strength, chose a different strategy, one reminiscent of its success with the shirt-pocket transistor radio five years earlier. The firm was Sony Corporation, and it introduced a small, lightweight transistorized monochrome receiver with a tiny 8-inch screen at the Chicago Music Show in July 1960, a year before launching it in the American market. Sony was apparently undaunted by the market failure of miniature receivers made in the United States or by U.S. market forecasts. In 1960 the trade press was quoting industry representatives as asserting that significant numbers of American consumers would never buy sets with screens smaller than 17 inches.

But those assertions were wrong. Although transistors were still expensive and the "micro" television sets were a luxury item ($250 when discount houses were selling middle-of-the-line 21-inch sets for under $150), those little sets were unique. In an innovative approach to distribution, Sony established its own sales subsidiary for the United States and sold the micro-receivers directly to department stores and other large retailers. Promoted by a highly creative advertising campaign, sales zoomed, rapidly outstripping the still small company's ability to supply the product.

Other Japanese companies soon followed Sony's example, but the U.S. television industry was slow to respond. Not until late 1963 did General Electric (G.E.) become the first company to make a set in this category, an 11-inch transistorized portable. Although most of the other U.S. brands soon filled out their lines with small-screen sets, it was usually with Japanese-made products. The Japanese thus established a base in small-screen sets from which they could expand to larger models, and eventually into color.

The numbers tell the story. United States imports of Japanese television sets had been negligible in 1960, but the success of micro-television boosted imports to 120,000 units in 1962 and a million in 1965—one in eight of the monochrome sets sold in the United States. Eighty percent of the Japanese imports had screen sizes of 12 inches or less, representing substantially all of the market for that segment. American companies, now concentrating on the accelerating demand for color receivers, helped boost the demand for these Japanese monochrome sets, for fully 70 percent of the Japanese imports bore American brand names.

COLOR TELEVISION

In the late 1960s the big story in consumer electronics was color television. Color television first took off in the American market, where demand grew from $50 million in 1960 (of $800 million total television receiver sales) to a 1969 level of $2 billion annual factory sales, or 80 percent of all televisions sold. Japan's domestic demand began in 1967 and grew rapidly until 1973. The European color television industry, unable to agree on a technical standard until 1966, did not grow significantly until the early 1970s.

Worldwide factory sales of television receivers (monochrome and color) totaled $6 billion in 1969, with the United States and Japan sharing over three-fourths of those revenues equally. Because color television was an American innovation, pioneered by RCA, one might have expected that the main consequence of its spectacular growth would be to cement the position of American firms as leaders in the world's television manufacturing industry. But the Japanese firms in this industry had already pulled even with the U.S. in total output—at about $2.3 billion in television sets—and were well on the way to establishing the dominant position they now hold. Japanese firms accomplished this feat in the 1960s by absorbing, then extending foreign technologies; developing a skilled labor force and advanced manufacturing techniques; exploiting their robust domestic market; and adopting export-oriented strategies.

The industry's technological leaders in the 1950s and 1960s had been RCA and N.V. Philips. RCA shared its color television technology under license, as it did all its technical achievements, with firms around the globe. This policy generated significant income over the years for RCA, but it also facilitated foreign entry into the field. N.V. Philips concluded an important agreement with Matsushita in 1952, giving the Japanese firm access to technology in semiconductors, picture tubes, and other key components. Matsushita Electronics Corporation, a joint venture between Matsushita and Philips soon became the largest Japanese producer of these components and a technological leader in its own right. The audio tape cassette, probably the most significant advance in audio magnetic recording, was invented by Philips in the early 1960s and soon licensed to Sony, Matsushita, and other Japanese firms who later became leaders in the consumer audio recording market.

While furthering the technological development of their products, the leading Japanese electronics firms also invested in improved manufacturing processes and in maintaining a highly skilled work force; these steps too proved a competitive advantage in the long run.

Japan's large domestic market for consumer electronics, second only to the United States in demand, was also important in the growth of Japanese firms in the 1960s. Behind protective barriers that limited foreign entry, the Japanese firms competed fiercely against each other. New technologies were first introduced on the local market, often as important weapons in their competitive rivalry. Although exports were taken seriously, domestic sales accounted for 60 percent of the revenues of the Japanese consumer electronics producers in 1969.

With exports and domestic sales combined, Japanese producers accounted for nearly two-fifths of the worldwide output of consumer electronics products in 1969, in a country representing only one-quarter of world demand. By then Matsushita, which was the largest Japanese firm in the industry, was the equal of the industry giants—RCA and Philips—with about $1 billion sales in consumer electronics. Moreover, the Japanese were now taking the lead in technology; in 1968 and 1969 two of the most significant technological innovations in color television emerged from Japan: Sony's Trinitron picture tube and Hitachi's all solid-state color receiver.

With this foundation, the Japanese were prepared in 1970 to take on a new challenge, pioneering in technology for the next major new product in home electronics, the home videoplayer.

CONSUMER VIDEOCASSETTE RECORDERS

The videocassette recorder is an innovation of the 1970s. To understand how it came about, however, we must again return to the 1950s. Videorecording, like the transistor and color television, was an American innovation. The first practical videotape recorder, which brought important changes in television broadcasting, was introduced by Ampex Corporation in 1956. The machine, called the Quadruplex (or Quad),[9] generated worldwide sales and set the standard for broadcasting use for two decades. Although RCA began producing videotape machines in 1959, Ampex continued to dominate the broadcasting markets, and to maintain technological leadership in the Quad family of machines.

In Japan, engineers of more than half a dozen electronics manufacturers called regularly at the studios of NHK, the national television network, to examine the Ampex Quad and pore over its equipment manuals, conferring among themselves and with the NHK engineers. Officials of the Ministry of International Trade and Investment (MITI) encouraged this interest, giving a small grant to at least one firm to develop videotape technology. Sony, out of its own funds, immediately mobilized a team for the same purpose. Dr. N. Kihara, who had experimented with video recording earlier in the 1950s, headed the team, under the direction of K. Iwama (later president of Sony).

The Quadruplex machine was a massive, complex, and expensive machine filling a large console and two equipment racks. In its monochrome version, it sold for $50,000. The complexity was necessary to produce a signal that met the stringent requirements of broadcast use. As early as 1955, however, Ampex engineers had experimented with an alternative approach, later called helical recording (because early designs wrapped the tape around the rotating cylinder along a helical path). Although the helical recorders also used a rotating head, they were much simpler to make and use than the Quad machines. Early helicals produced pictures that were adequate in quality for the general public, but utterly inadequate for the only customers then interested in video recording—the broadcasters.

The Ampex developments in helical technology remained secret until 1962, but a Japanese firm, Toshiba, shocked the industry in 1959 by announcing its patent for a videotape recorder using a helical format. It was clear to engineers that machines built on the helical design could be made smaller and cheaper, and would thus be suitable for many uses outside of broadcasting. Not so clear, however, was which path to follow in developing the technology, how to develop new markets for the resulting products, and how good a business it would be once products and markets were developed.

During the 1960s, firms in the United States, Japan, and Europe participated in the technical and commercial development of helical recording. Outside Japan the leaders were Philips, which dominated European professional and broadcasting markets for video recorders, and Ampex, which extended its broadcast leadership in the United States with a line of professional and industrial units. But neither Philips nor Ampex was focusing on a consumer product at this time. Ampex had always been oriented toward broadcast and professional markets, with consumer products only a minor part of its business, and Philips's consumer divisions were not involved in video recording at all. None of the leading American consumer electronics firms invested significantly in video recording until after 1970.

In Japan, by contrast, eight or more companies—including all the leading consumer electronics manufacturers—launched aggressive efforts to develop helical video recording technology. Sony and Matsushita, among the first to succeed in marketing a consumer product, were consumer electronics companies whose goal, from the very beginning, had been to achieve a design suitable for the home market—even though they sold their first products in other markets. In Matsushita's labs, as early as 1959, an engineer wrote a paper recommending development targeted toward a consumer market, complete with a technical analysis showing the feasibility, in principle, of achieving adequate levels of performance and efficiency. Even earlier, at Sony, Kihara's team first replicated the Quad machine—with knowledge gleaned from the Ampex model, but without aid from Ampex engineers—in just a few months. They then set to work on the helical format, guided by a mandate from the company's founder and chief executive, M. Ibuka, who challenged them to build a machine that would cost 1 percent as much as the Quad and could be sold to consumers.

Technical progress, viewed in retrospect, was dramatic, as Table 3 indicates. The first Sony product, in 1963, was one-twentieth the size and one-fifth the price of the Ampex Quad. By 1965 Sony could market a helical machine that used a half-inch tape (versus the more costly two-inch tape of the Quad) and sold at the price that met Ibuka's goal: 1 percent (in constant dollars) of the original Quad machine. Matsushita had a comparable design, and both were shown at the U.S. Consumer Electronics Show in 1965, prompting Ampex to proclaim its intent to market a consumer model the next year.

Despite the fanfare, the videotape recorder of 1965 was still far from being a consumer product. It was still monochrome when the shift to color was already under way. It required manual threading of the tape when experience with the audio cassette had proved that ease of loading made a big difference in consumer demand. And it still used prodigious amounts of very expensive recording tape—even if eight times more efficiently than the Quad format.

Then came the videocassette. By 1970, the first-generation helical cassette machines, developed by Philips in Europe and by several companies in Japan, were ready for demonstration. A worldwide public relations carnival ensued as the press decided that the age of cartridge television in the home had arrived. But they were wrong. Although the technical base was there, it would take until 1975 to develop and market the first successful consumer videoplayer. Meanwhile, in the early 1970s, RCA, Avco, Ampex, and others sought to introduce consumer cassette recorders and failed; Sanyo, Toshiba, and Matsushita did the same. The only commercially successful products at this stage were destined for professional and industrial use. These were the Philips videocassette recorder, dominant in Europe, and Sony's U-Matic, which set the standard for the now

Table 3—Milestones in VTR Product Development

Market	Model	Company	Date of Commercial Introduction	Tape Width*	Tape Utilization (sq. ft./hour)	Price (in constant 1967 $)
Broadcast	VR-1000	Ampex	1956	2"	747	$60,000
Professional	VR-1500	Ampex	1962	2"	375	12,000
Industrial	PV-100	Sony	1962	2"	212	13,000
Industrial/ Professional	EL-3400	Philips	1964	1"	188	3,500
Industrial/ Professional	CV-2000	Sony	1965	1/2"	90	600
Industrial/ Professional	N-1500	Philips	1972	1/2"	70	1,150
Industrial/ Professional	U-Matic	Sony	1972	3/4"	70	1,100
Consumer	Betamax	Sony	1975	1/2"	20	850
Consumer	VHS	JVC	1976	1/2"	16	790
Consumer	VR-2020	Philips	1980	1/2"	6	520

*From 1972 onward, all models used cassettes instead of open reels and all used high-energy tape.
Source: Authors.

ubiquitous three-quarter inch "U-format" adopted by Matsushita and Japan Victor.

In the Sony lab, Kihara and his associates took the next logical step beyond the U-Matic and produced the now legendary Betamax, which was ready for commercialization by early 1974 and on the Japanese market in mid-1975. By eliminating the guard band between recording tracks and exploiting the limits of technology in both heads and tapes, Sony designers reduced the amount of tape needed to record an hour of program by 70 percent. Less tape permitted a smaller, less expensive cassette, which in turn permitted a smaller recorder.

Within two years, engineers at Japan Victor, adopting some of Sony's innovations and adding variations of their own, had perfected an alternative design. Termed VHS (Video Home System), it was adopted by Japan Victor's parent firm, Matsushita, and now shares the bulk of the world market with Sony's Beta format.[10] Matsushita announced the production of their two millionth VHS machine in late 1980; Sony's sales of Betamax machines reached 750,000 units in 1980 alone. The sole competitor to these products is an innovative Philips design, called the VR-2020, which is also produced under license by Grundig in Europe. Volume manufacturing operations for the Philips VCRs were starting up in 1980.

THE INGREDIENTS OF SUCCESS

What were the main ingredients of success in the videocassette recorder innovation? Why did the American consumer electronics industry fail totally to establish a manufacturing position in this field? These questions have no simple answers. Any answers proposed at this point are open to challenge. Despite the recency of events and the incompleteness of the record, we offer our interpretation as a working hypothesis.

One key to understanding any innovation is to look at the technology. Whereas Ampex's long dominance of the broadcasting market was won by a single brilliant development produced by a small team in a few years, the home videocassette recorder was developed step-by-step over twenty years, interactively, by nearly a dozen companies worldwide. Various technical advances had to be combined to produce the necessary features and level of performance for the consumer market—advances in magnetic materials for recording tape and recording heads, and in micro-electronic circuitry, coupled with imaginative design of tape formats, tape-handling systems, and video circuit design. The engineers at Sony, Japan Victor, and Matsushita contributed important inventions, but their Beta and VHS machines also contain many elements invented by Ampex, Philips, and Toshiba, whose success in the videocassette recorder business is much more limited.

The successful firms in home video, then, are not distinguished from the rest by inventiveness. No single technical advance unlocked the door to engineering and market success. The successful firms are those whose engineering efforts integrated the technologies for the home videocassette recorder. Several conclusions emerge from a review of their efforts.

First, in view of the large number of Japanese firms competing to develop video recording technology, it is not surprising that the VCR innovators were Japanese. In the early 1960s, substantial development efforts existed at Toshiba, Matsushita, Sony, Japan Victor, Sanyo, Ikegami, Akai, Shibaden, and perhaps others. Outside of Japan, only Ampex and Philips appear to have mounted comparable development efforts at that time.

While the Japanese electronics firms were developing video technology, they were also investing in their manufacturing systems, nurturing employee relations, effectively engaging the skills of employees at all levels, introducing innovative manufacturing processes, and emphasizing quality and productivity throughout. They did so with a view not only to current requirements, but to constant improvement for the future. Such steps enabled the major Japanese companies to develop production capabilities superior to those of most American and European firms.

Furthermore, many of these Japanese firms (and especially the three ultimate leaders) were specialists in consumer products. In contrast, Ampex focused on government and broadcast markets, and Philips was highly diversified. (See Table 4.) Development efforts at Sony, Matsushita, and Japan Victor began with a consumer product as an ultimate goal. In Sony's case the goal included a clear definition of a target cost, imposing an important economic discipline on development.

Finally, there was the element of persistence. All of the participants in development of the technology tried to commercialize a consumer product prematurely and failed. The Betamax was in fact the fourth videorecorder generation demonstrated by Sony as a ''consumer'' product. In 1973, Matsushita geared up an entire department of 1,200 employees to produce a home videocassette recorder that failed utterly in the market. The three current leaders seem to have been able to maintain a strategic commitment that kept development going in the face of disappointment and failure, a strategy similar to that of the more publicized Japanese automotive industry, which had persisted despite initial failures with products first introduced in the U.S. market. They remained committed to small cars, gradually improving product performance, quality, and attractiveness to U.S. consumers. These improvements, combined with increased productivity, have given Nissan, Toyota, and Honda a quality and production position superior to that of U.S. automotive manufacturers.

Table 4—Strategies of Major Consumer Electronics Producers: 1969

Company	Total Sales (Million)	Consumer Electronics	Home Appliances	Subtotal
Consumer Electronics Specialists				
Zenith	$ 677	90%	nil	90%
JVC	300	90	nil	90
Sony	300	80*	nil	80*
Consumer Electronics and Appliance Specialists				
Sanyo	$ 500	47%	37%	84%
Matsushita	2,100	50*	25*	75*
Diversified Majors				
Philips	$3,600	28%	10%*	38%*
RCA	3,200	33*	nil	33*
G.E.	8,445	5*	N.A.	<20*
Hitachi	2,300	20*	28	≤50*
Toshiba	2,200	20*	20*	41

*Authors' approximations.

Sources: Company annual reports; SEC filings; *Japan Company Directory*, 1972 (The Oriental Economist).

The successful innovators in the home videocassette recorder turned out to be, then, consumer electronics companies that had long pursued a global ''high technology'' strategy. Their managements foresaw consumer applications of video recording 15 years before the market could actually be tapped, and persisted in their commitment to develop the basic technology even when prematurely commercialized consumer products failed in the market. They had a highly skilled labor force, and invested significantly in advanced manufacturing processes. And they were quick to respond to the success of others.

In contrast, the American consumer electronics industry in the late 1950s and throughout the 1960s was held captive by a different ideology. Managements responded to the 1950s market saturation and shake-out by cutting costs. One technical manager said that the standing orders from the television division were to offer them ''any new technology available, as long as it gets cost out of the product.'' Product differentiation was sought in advertising ''images,'' and in such attributes as styling, rather than in performance.

Furthermore, the American industry never developed markets abroad. A senior Zenith executive (later to become the company's chief executive officer), told a Harvard Business School casewriter in early 1972 that ''we've always had our hands full with U.S. demand and we've always tended to stick with the biggest payoff and what we knew how to do best. For example, an additional two market share points in the Los Angeles area alone represents more sales volume than there is in most foreign markets.''[11]

American managers tended to rely on market research and ''objective'' analysis to identify latent market opportunities, whereas firms like Sony took risks on novel products and set out to develop the market. For example, in 1955 G.E. had attempted, prematurely as it turned out, to develop the second-set market in the United States with a small-screen monochrome television. In June 1960 (a month before Sony unveiled its micro television, G.E. management returned to the idea and commissioned market research in which mock-ups of sets of eight different screen sizes, weights, and prices were shown to interviewees. The study concluded that "people do not place a high value on portability of the television set."[12]

Throughout the 1960s, while firms like Zenith, G.E. and RCA treated consumer electronics as a mature business with few opportunities for technological leadership, Sony, Matsushita, and JVC did the opposite. In radio and then in monochrome and color television, they sought to apply advanced technology to enhance product value to the consumer. Even when domestic demand was brisk, they began to build positions in export markets, starting with the largest (the United States) and aiming at a niche overlooked by the U.S. industry. After initial success, they broadened their lines and deepened penetration.

Their consistent adherence to a high technology strategy enabled Sony, Matsushita, and JVC to take the lead in the videocassette recorder mass consumer market. The technological advantage gained through this strategy was an important ingredient of their success. For example, although U.S. firms designed and built the first miniature all-transistor radios in the 1950s, Sony developed the first product to be successful in the mass market. By capturing the major share of world markets for small radios, Sony and other Japanese producers gained the lead in experience with consumer applications of the transistor. Adapting the transistor to other audio, and later, video products, these firms extended their lead. Similar aggressive strategies in another market segment, audio tape recorders, provided the basis for advantage in another important technology, ferrite recording heads.

Although the largest American firms in the industry, such as G.E. and RCA, also had major technical resources, they were unable to bring them to bear on consumer market opportunities. Some of the barriers limiting their effectiveness in using new technology were organizational. For example, one of the earliest designs for an all-transistor miniature portable radio was developed in the mid-fifties in the corporate lab of one of the giant American companies. The link to the company's own radio business was never forged and the circuit was licensed to a Japanese producer who incorporated it into products sold successfully in the United States. Later, the American firm's radio business, in an attempt to catch up, made a photocopy of the Japanese circuit board as the basis for their own design, only to learn that they were copying their own lab's invention. Moreover, the low priority given by the principal U.S. firms to technology for consumer electronics limited their ability to create the technological base necessary to compete in the manufacture of videocassette recorders.

Nor did U.S. firms develop production capabilities competitive in either efficiency or quality; instead they moved their manufacturing facilities to low-cost labor areas like Taiwan or Hong Kong, or purchased foreign products. They also failed in most cases to develop the unique manufacturing techniques that might have given them a cost, quality, or performance edge.

Sony, Matsushita, and JVC, unlike most of their American and European competitors, were able to implement their technological strategies through a distinctive organizational system. Technical and commercial staffs at Sony and Matsushita appear to work together effectively, to share information, and to understand common goals. Top-level executives, including the chief executive officers, maintained the close contact with the persons developing the new technology that made it possible for their firms to respond rapidly to developments in a constantly changing field. In contrast, the long-established U.S. firms had to contend with organizational barriers between technical staffs and operating businesses, as illustrated by the transistor radio example above. Their top managers were preoccupied with other priorities and did not involve themselves deeply in VCR technical or marketing issues. Nor did Philips's management; a hint of the significance of these internal factors can be seen in their response to the Betamax invention. Philips employs a complex and sophisticated organizational structure and resource allocation system to manage its multiple businesses in many countries around the world. While offering many advantages in other respects, that complex organization may have been a real handicap in this innovation. VHS, the Japanese alternative to Betamax, reached the market only 18 months after Sony; it took Philips more than five years to produce their response, the innovative System 2020.

Although the innovative success of Sony, Matsushita, and JVC can be attributed primarily to their strategies and organizational methods, they also benefited from their location in Japan. In all of their consumer electronics businesses they served a large protected domestic market that provided the basic "bread and butter" for cash flow and growth. Furthermore, that market was not fragmented; the leading firms had large shares, giving them a significant scale of operations. The U.S. manufacturers also had a large, concentrated domestic market, but they lacked two things the Japanese had from the start—access to an even larger foreign market, and protection against import competition.

The human resource base in Japan may also have provided an advantage. Sony and others could draw on an educated, motivated, and stable work force and thus capitalize on skills built up within their companies through the custom of lifetime employment. Because of a unique manufacturing style that integrated effective, if not entirely original, methods of labor management with Japanese cultural traits, the Japanese developed quality and productivity levels that exceeded U.S. capabilities by as much as two to one.

Finally, certain basic cultural factors are evident in Japan's national industrial ideology, which is oriented toward improved quality and efficiency, toward worldwide marketing, and toward evaluation of performance on the basis of long-term rather than short-term results. In the context of these underlying management assumptions, the Japanese approach to consumer electronics seems almost inevitable. In terms of the American assumptions, it makes little sense—which brings us back to our main point: at the core of the problem of American competitiveness are the attitudes and practices of American managers.

MANAGERIAL ATTITUDES AND PRACTICES

In recent years, the managers of U.S. industry have increasingly preferred to make choices based on abstract analysis of seemingly objective considerations rather than on the insights and judgment of persons seasoned in a business. Concern for near-term financial performance often outweighs long-term considerations. Together, these tendencies produce strategic behavior that is largely reactive. Confronted with effective foreign competitors pursuing proactive strategies, American firms seem to be losing ground.

Not all U.S. firms can be characterized this way, of course. IBM and Texas Instruments, for example, are firms led by managers who combine long-term perspective with deep knowledge of current operations.[13] But these are exceptions to the rule.

It is conventional wisdom that the "push" of new technology yields the greatest rewards when guided by the "pull" of the market. But the paradox of this formulation is that the market's "invisible hand" is expressed through transactions that are possible only after the technology is developed. Hence the rise, in Chandler's apt phrase, of the "visible hand" of the modern corporation to guide the develtpment of technology in anticipation of market rewards.

In many American firms, the methods used to do that job seem to have gotten out of balance, as inappropriate use of common marketing concepts thwarts the incorporation of new technology into innovative products. As illustrated by the contrasting experiences of G.E. and Sony with small-screen television, the needs expressed in the market tend to reinforce the status quo because standard market surveys measure what the customer knows he or she wants now. The initial market estimates for computers, xerographic copiers, the Land camera, and other major innovations, for example, fell short by factors of thousands. Successful innovators look beyond expressed needs and lead the market through technologically innovative products that meet latent needs. Formal market analysis is often useful, but should not dominate resource allocations to product development.

The very phrase "technology push"[14] may tend to overstate technology's role in the successful introduction of radical innovations. When an innovation captures the market by introducing technologies that address latent needs, significant efforts to educate users about its inherent possibilities have usually been made. The successful videocassette innovators illustrate this point; Sony's brilliant initial advertising of the Betamax as a "time shift" machine is a classic example.

The point is not that product development strategies should always be geared toward latent rather than expressed consumer needs, but that management attitudes and practices geared to the quantifiable and provable, the here and now, risk the loss of such opportunities to use technology to gain competitive advantage.

The conventional wisdom about so-called "mature industries" entails a similar risk of missed opportunities for use of new technology. Mature markets may offer little objective evidence of readiness to accept innovative products, and it is common wisdom for firms competing in them to direct their main efforts to advertising, promoting, or reducing the prices of established products. Yet attention to customer needs can reveal opportunities for rewarding investments in technology to differentiate products in performance terms.

The assumption that competitive priorities should change systematically along the life cycle of a product is valid, but should not be followed blindly. The potential value of technological advances in products and processes does not decrease simply because known customer needs have been met. While U.S. managers in the television industry were focusing on volume expansion and cost reduction when growth leveled off, Japanese firms like Sony continued to study latent consumer needs and to introduce major product improvements. Management approaches that operate according to stages in the life cycle create major competitive handicaps if they discourage continuing innovation to meet underlying customer needs.

The biases in management concepts that favor analytic rather than experiential evidence and short-term rather than long-term results are reinforced by parallel tendencies in today's systems of financial control. Three trends have shaped current U.S. practice: (1) increasing diversification of the businesses engaged in by a single firm; (2) consequent decentralization of operations to semi-autonomous "profit centers"; reinforced by (3) the emergence of "scientific" theories of corporate finance.

Since the 1950s, a penchant for diversification has led U.S. firms farther away from their core technologies and markets than it has their counterparts in Europe or Japan. Managers in the United States appear to have an inordinate faith in the portfolio law of large numbers, which holds that to amass enough product lines, technologies, and businesses, is to cushion against the random setbacks of life. This may be true for portfolios of stocks and bonds, where considerable evidence shows that setbacks are random, but businesses are subject to both random setbacks and carefully orchestrated attacks by competitors. Thomas J. Peters, of McKinsey and Company, in discussing ten well-managed and successful U.S. companies, notes that all are exceptions to this tendency; each, he says, "is a hands-on operator, not a holding company or a conglomerate." Moreover, he argues, "these companies have achieved unusual success by sticking to what each knows best," resisting the temptation to move into new businesses that look attractive but require corporate skills they do not have.[15]

The more general trend toward diversification has reinforced and been reinforced by application of modern theories of financial portfolio management. These principles have increasingly been applied to the creation and management of corporate portfolios, or clusters of companies and product lines assembled through various modes of diversification under a single corporate umbrella. When applied by a remote group of dispassionate experts primarily concerned with finance and control, who lack hands-on experience, the mechanics of portfolio analysis and related resource allocation push managers even further toward an extreme of caution.

The top managers of highly diversified firms necessarily find themselves unable to relate their own experiences to the vital issues of their operating businesses. Since most of these firms use decentralized organizational structures, the manager of each profit center can be held primarily accountable for results. But how does the top manager judge the operating manager's strategic expenditures if they are risky and unlikely to produce near-term results?

Tendencies toward the near term, and toward quantifiable results, produce a situation in which many American managers—especially in mature industries—are reluctant to invest heavily in the development of new manufacturing processes or creative work force policies. By ignoring the competitive advantage of the latter, as in the case of the automotive industry, they adopted homogenous labor relations as dictated by industry unions. This shortsighted action has limited the scope of competitive maneuvers, and left the field of work force productivity to foreign competitors. And many U.S. managers assume that essential advances in process technology can be more easily accomplished through equipment purchase than through in-house equipment design and development. This assumption is less widely shared abroad. Although managers overseas often seek to increase market share through internal development of advanced process technology, even when their suppliers are highly responsive to technological advances, managers in the United States often restrict investments in process development to those items likely to reduce costs in the short run. This diminishes the opportunity for competitive differentiation. Even if companies develop significant new products through aggressive R&D, to the extent that they use established process technology, they reduce their competitors' lead time for introducing similar products. Not only can investing in the development of process technology make products more profitable, when it yields a proprietary process it can serve as a formidable competitive weapon. Indeed, the barrier to entry into videocassette recorder manufacture by U.S. firms is their lack of process know-how. The product technology is open to all; the real secret lies in the Japanese factories.

In sum, we find that certain "modern" strategic concepts, analytic methods, and organizational practices discourage the kind of long-term perspective and risk taking necessary to sustain a high level of technological innovation. We may wonder why the negative consequences of these attitudes and practices have become evident only in recent years. A confluence of trends at work over several decades has resulted, we believe, in a significant shift in balance. Paralleling the trends toward corporate diversification, decentralization, and use of new concepts of financial management is the growing acceptance of a certain concept of the "successful manager."

There is widespread belief in both the business community and academia in a concept of the professional manager as a "pseudo-professional"—an individual with no special expertise in a particular industry or technology who nevertheless can step into and successfully run an unfamiliar company through strict application of financial controls, strategic concepts, and market analysis. Although we do not believe that major competitive choices can be made without careful attention to basic marketing and financial issues, we fear that apparently sophisticated analysis of these factors can mask a shallow understanding of customers and a shortsighted view of financial objectives. Moreover, no matter how well these considerations are understood, they are inadequate without a complementary understanding of the technological issues.

It is a rare individual who commands the necessary depth of understanding in each of the major facets of business strategy: markets, finances, and technologies. Good organizational design ensures that the operations of the firm are rooted in specialized units able to concentrate on one of these dimensions. But as top management must blend the specialized knowledge, experience, and insight of each unit into an integrated, coherent whole in order to make strategic decisions for the entire company, the training and outlook of these integrators at the top of the managerial pyramid are directly relevant. If these individuals are interested in but one or two aspects of the total competitive picture, if their training includes a narrow exposure to the range of functional specialties, they may be unable to implement the necessary integration.

There have been substantial changes over the last two decades in the training and experience that top executives bring to their jobs. Companies have been placing greater value on education and less on experience. The nation's business schools have produced increasing numbers of MBAs armed with knowledge of the latest concepts and faith in their efficacy. No longer does the typical career provide future top executives with intimate hands-on knowledge of the company's technologies, customers, and suppliers. Since the mid-1950s, the percentage of new company presidents whose primary interests and expertise lie in the financial and legal areas rather than in production has substantially increased.[16] In addition, many American companies continue to fill new top management posts from outside their ranks. In the opinion of foreign observers, accustomed to long-term careers in the same company or division, "high-level American executives seem to come and go and switch around as if playing a game of musical chairs at an Alice in Wonderland tea party."[17] In Japan, by contrast, executives spend a lifetime in one firm where, increasingly, it is the technical man who becomes the chief executive officer.

Trends in management attitudes toward technology and innovation offer another explanation of the emergence in the 1970s of changes in performance. World War II gave great impetus to technology-based innovation and growth in industry. Belief in science and technology was sometimes carried to extremes, as symbolized by lavishly funded corporate research centers established in country-club settings. As this impetus faded, in the 1960s, managers shifted emphasis toward incremental improvements and efficiency gains, a tendency that has been carried to extremes in the 1970s.

Some of these trends have run their course and even been reversed. Since 1976, the expenditure of industry funds (as distinct from government funds) on R&D has risen faster than inflation. Pace-setting companies like G.E. and du Pont are reemphasizing technology and innovation. Significantly, John Welch, G.E.'s new chief executive, and Edward Jefferson, the new chairman at du Pont, are Ph.D. chemists with experience in important innovations within their companies.

Although these are straws in the wind, they suggest that fundamental and widespread changes in prevailing attitudes and practices are possible in the 1980s.

CONCLUSION

> The fault, dear Brutus, is not in our stars, but in ourselves.
>
> —*Julius Caesar*, Act I, Scene 2

How can the institutional climate in America be made more favorable for industrial innovation? If our analysis of America's declining competitive position is valid, fundamental changes in the attitudes and practices of management are needed to reverse—or halt—this decline. We view these changes as a return to values once well-established in American industry—the ability to think toward the future, the willingness to innovate and to take bold risks in developing new technologies, new markets, and highly productive manufacturing systems. But we also believe that these changes may require the adoption of new, creative policies toward labor relations and toward cooperation with government and universities.

Among the attitudes hindering American competitiveness has been the tendency to neglect product and process technology as a competitive weapon. Senior managers who are inadequately informed about their industry and the nature and interactions of its parts suppliers, workers, and customers, or who have little incentive to consider the long-term implications of their own decisions, are more likely to display this tendency. Tight financial controls with short-term emphasis will also bias managers toward choosing the less innovative, less technologically aggressive alternative. Attitudes that preclude creative work force policies are all too common. The character of competition also plays a role. Recent Japanese success in the automobile and consumer electronics industries is partly the result of long-standing technological and market rivalry among several strong firms; others have been quick to match a successful innovator's formula. The key question is, then, how these tendencies can be changed to foster competition, encourage long-term development of basic technologies, stimulate the often risky commercialization of the results of successful technical efforts, and maximize work force effectiveness.

Government policies affect industry both directly and indirectly. Policies and programs that have an important impact on industrial innovation—tax structure, monetary policy, regulation, patent policy, and aspects of national science policy—have become primary considerations. These broad policies may nurture the scientific and engineering professions and the economy in general, but they fail to provide sufficient conditions for realization of the potential for industrial innovation.

The government may also try to create incentives for long-term research and development, to cushion the risks of innovation, and to encourage competition. But the correct approach is as yet unclear, because the linkages between advances in science and technology and such economic outcomes as productivity and innovation are not well understood. Government agencies can reduce the financial risks of investment in advanced technology, as they have in the past, by serving as customers for innovative products. There are other areas of potential influence: the Carter Administration's Domestic Policy Review of Industrial Innovation recommended changes in the tax treatment of technology, but these were never endorsed by the President. Nor is the impact of the Federal Trade Commission and Justice Department always clear; in many cases their rules may in fact thwart innovation. In the U.S. consumer electronics industry in 1955, for example, the companies involved met most economic tests for a vital industry free of monopoly and barriers to entry, yet innovations failed to emerge.

Universities can facilitate long-term development of new technologies by continuing to explore ways of structuring relationships with industry. History suggests that industries with healthy links to first-quality academic work are more robust. The U.S. semiconductor industry and German chemical industries are cases in point. In certain frontier areas of engineering—robots or computer-aided design—U.S. industrial firms are already collaborating with university laboratories, by supplying money and assigning technical personnel to work on the programs. Complementary programs in which university personnel have access to state-of-the-art equipment and techniques within industrial laboratories may also prove mutually beneficial. F. Karl Willenbrock, Dean of the School of Engineering and Applied Sciences, Southern Methodist University, has suggested the possible development of engineering analogs to the medical profession's teaching hospitals, where practice and education coexist.[18] In the field of science, interesting new approaches include the 12-year program of biomedical research sponsored by Monsanto at Harvard Medical School, and the 10-year program of research on combustion processes sponsored by Exxon at the Massachusetts Institute of Technology. Universities, by their nature, have advantages in continuity of personnel and long-term perspective; industry brings not only resources, but vital information about relevant practical needs.

Management faculties might also reflect on some unintended consequences of current methods of management education. Many of the dysfunctional attitudes and practices discussed here are clearly related to what is taught in financial analysis, marketing, planning, and related fields. Research designed to clarify the relationships between technological advances and economic outcomes would also be a valuable university contribution.

As essential as cooperation between industry, government, and universities may be, opportunities for it are severely limited by the nature and complexity of American business. We believe that the primary agents of change must be industry's top managers themselves. They provide the real leverage, for senior executives make the most significant decisions. If they are well informed, experienced, and committed to excellence and innovation, they can effect the changes that will creatively tap this country's human and natural resources and put American industry back into the competitive position it once held throughout the world.

NOTES AND REFERENCES

1. This idea is developed in "Technological Innovation in Firms and Industries: An Assessment of the State of the Art," by Richard S. Rosenbloom, in P. Kelly and M. Kranzberg, eds., *Technological Innovation: A Critical Review of Current Knowledge* (San Francisco: San Francisco Press, 1978).

2. The contributions of several colleagues who helped shape this paper are gratefully acknowledged, including the work of Karen J. Freeze in assisting in its development.

3. The contrasts noted in this example should not be extrapolated to Japanese and American industry generally. There is some evidence to suggest that the particular Japanese firms examined here are not typical of industry in Japan.

4. Public Law 96–480.

5. Robert H. Hayes and William J. Abernathy, "Managing Our Way to Economic Decline," *Harvard Business Review*, vol. 58 (July-August 1980).

6. The judges included four chief executives of business, two professors (neither from Harvard), and one government official. The editors are unable to recall a previous case where the vote was unanimous.

7. Consumer electronics is a durable goods manufacturing industry whose principal products are television receivers, radios, phonographs, and audio and video tape recorders.

8. For an interesting summary and interpretation, see George R. White and Margaret B. W. Graham, "How to Spot a Technological Winner," *Harvard Business Review*, vol. 56 (March-April 1978). The transistor, invented at Bell Laboratories in the U.S., was the invention that opened the door to the creation of the semiconductor industry in which American firms have had leading positions. But the application of the transistor to consumer products is a field in which Japanese firms pioneered.

9. The name derives from the use of four magnetic recording heads, located on the edges of a rapidly rotating drum in contact with a tape that moves laterally past the drum.

10. Japan Victor is quick to point out that the development of the VHS was launched well before they became aware of the Betamax and was an independent invention.

11. Zenith Radio Corporation, Harvard Business School case study, 9–674–095.

12. G.E. subsequently introduced a model with 19-inch screen at a low retail price. Interestingly, the research had shown the "most preferred" mock-up to be one with a 10-inch screen with 18-pound weight, priced at $259 if transistorized, or $129 in a tube version—not unlike Sony's successful design. Source: General Electric Radio and Television Division, Harvard Business School case study, 9–513–082, 1967.

13. An interesting characterization of America's best-managed companies is given by Thomas J. Peters in "Putting Excellence into Management," *Business Week* (21 July 1980), pp. 196–205. Peters analyzes the ingredients of successful management in 10 well-run companies, including the two mentioned here.

14. The shortcomings of "technology push" strategies in the public sector have also been noted. Abernathy and Chakravarthy argue, in "Government Intervention and Innovation in Industry: A Policy Framework," *Sloan Management Review* (Spring 1979), that government attempts to innovate through technology push alone have usually failed. Complementary efforts at "technology pull" through intervention in

products and markets seem to have been associated with most successful cases.

15. Peters, "Putting Excellence into Management."

16. See Exhibit VII in Hayes and Abernathy, "Managing Our Way to Economic Decline."

17. Not all U.S. companies fit this description. Some well-known companies that emphasize promotion from within—for example, IBM, 3M, Texas Instruments, or Citicorp—are also well known for risk taking and innovative success.

18. "Engineering—the Neglected Ingredient," remarks at the Science Policy Seminar, The George Washington University, 9 December 1980.

3 Decision-Making With Modern Information and Communications Technology: Opportunities and Constraints

*Donald J. Hillman**

THE GROWTH OF INFORMATION AND COMMUNICATIONS TECHNOLOGY

The growth of sophisticated information processing systems, accompanied by huge advances in telecommunications capabilities, constitutes an information revolution which raises significant new issues for policy makers. This paper analyzes the historical and recent developments in data processing and telecommunications, the impact these advances are having on society, and the associated policy issues which need to be addressed.

HISTORICAL PERSPECTIVE

A significant aspect of the growth of information and communications technologies is that the two technologies are merging. To gain a better understanding of this phenomenon, it may be helpful to examine three categories which comprise the information industry; for it is their interaction which forms the most powerful information processing and communications systems.

The functional categories of importance are:

- information and data processing technologies;
- word processing technologies;
- communications technologies.

Information and Data Processing

Information and data processing technologies are primarily associated with computers. Advances in computer performance have been spectacular, in both the variety and number of different applications. Advances in miniaturization have reduced computing costs substantially, thereby expanding the number of users and enlarging possible applications. Two basic architectural features of computers are involved in this rapid progress. The first of these is a *hierarchy of memories*. Memories range from slow, high-capacity peripheral devices (such as magnetic tapes and disks) to fast, limited-capacity central memories (such as magnetic cores or semiconductors) to high-speed registers.

The second feature is the central processing unit, which contains the arithmetic/logic unit and a control unit. The arithmetic/logic unit manipulates the high-speed registers according to logical operations. The control unit is responsible for examining the programmer's instructions, and controlling the actions of the memories and the arithmetic/logic unit to perform the necessary operations. Instructions and data are both stored in the same memory. In the future are fundamental architectural changes in computer design, which promise to increase performance significantly.

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Word Processing Technology

Word processing manipulates text without regard to message or semantic content. Text-editing, while closely identified with word processing, is used to align the formats of large multipage documents and reports, and to handle routine office correspondence. Word processing was applied initially to manual office functions, and it affected primarily secretarial and clerical workers. There is growing evidence, however, that word processing is beginning to make an impact on office operations in general, and that when linked with data processing, the combination will substantially alter future management styles.

Communications Technology

The telephone has been transformed from a signal transport device into a message processor capable of conference calling, call forwarding, automatic dialing, automatic redialing of busy numbers, and last number redialing. Digital data networks have greatly increased access to online information retrieval systems, and facilitated the transmission of large amounts of information between dispersed points. Facsimile transmission is widespread. Optical fibers can carry more simultaneous messages than conventional cable. Cable television has enormous potential for home information services, and videodisks and videocassette recorders could have a substantial impact on education as well as home entertainment. The publishing industry is being changed by the transmission of news and literature via telecommunications and broadcasting systems. Communications satellites provide the means for inexpensive, reliable, and real time information transfer on a global scale.

RECENT DEVELOPMENTS

It is the interactions amongst the functions of data processing, word processing, and communications that reflect the real potential for advancement. Traditional distinctions between telephone utilities, newspaper and book publishing, banking, and postal services are becoming blurred, and these blurred distinctions have generated important policy problems for both government and private enterprise.

In part, the issues have arisen because the electronic storage, manipulation, retrieval, and transmission of information are available at costs competitive with paper. Several key examples illustrate the rapid development that has occurred in information technology in recent years.

- The cost of computer main memory has been declining 26 percent per year since 1965, and is expected to continue to do so through the 1980s.
- There is now a full range of commercially available storage technologies which permit access times as low as a billionth of a second for the small high-speed storage used to process information.
- The new videodisks can store as many as ten billion bits of information on a disk the size of an ordinary phonograph record.
- The performance of central processors has increased at a rate of 35 percent per year since they first were introduced (see Figure 1), while costs have declined by about 20 percent per year (see Figure 2).

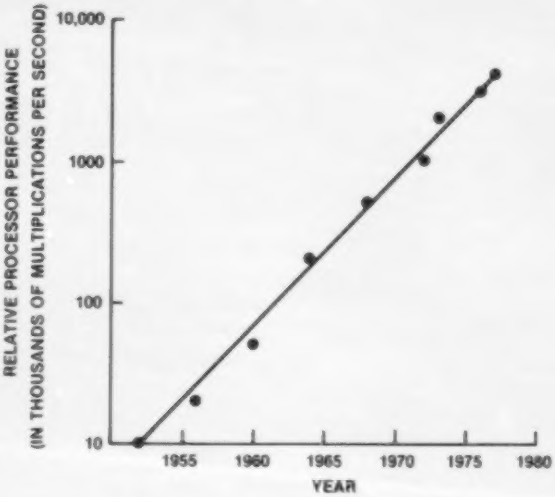

Figure 1. Relative Computer Processor Performance.

Source: Donald P. Kenney, *Microcomputers* (New York: Amacon Press, 1978).

- Circuit density is increasing dramatically, particularly in very large-scale integrated (VLSI) circuits. Integrated circuits now contain 100,000 active components; some estimates place the number at 10^9 by 1995.[1]
- Word processing devices are acquiring communications features which provide electronic mail functions as well as access to outside data-bases.
- Data processing combined with word processing provides a variety of information handling, storage, and retrieval capabilities within one system.
- The use of microprocessors in a number of office devices—from dictation equipment to photocopiers—has reduced equipment size and enhanced operations significantly.
- In the last 15 years, channel capacity of a single communications satellite has increased by a factor of 50, and the cost per circuit year has decreased by a factor of 45.[2]

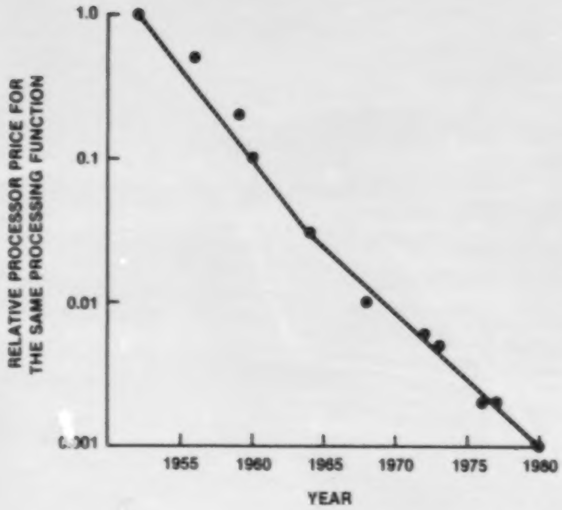

Figure 2. Relative Computer Processor Price.

Source: Donald P. Kenney, *Microcomputers* (New York: Amacon Press, 1978).

- Packet-switching has become an alternative to time-division and circuit-switched networks.
- Some new services combine satellite, microwave, and cable technologies for long-distance voice, data, and video transmission.

IMPACT OF INFORMATION TECHNOLOGY

The implications of these new tools are significant. Within the office, traditional operations are being altered as mid-level managers and technicians employ minicomputers to monitor work routines. Writers and editors enhance their efficiency through the direct entry of data to word processors. Portable terminals enable employees to work from their homes. Line managers can receive timely information from a variety of distant sources, thereby improving the decision-making process. In some cases, the choice of technologies—for example, large central processing unit versus distributed minicomputers—will substantially affect the way an enterprise functions.

New information handling methods are affecting the commercial world in a number of ways, as in electronic banking and consumer purchasing via remote terminals. Multinational corporations operate more efficiently in the international marketplace through the use of communications technology linked to information processing.

Computer technology is entering the home as well. Microprocessors imbedded in a variety of devices control temperatures or turn on the oven. Innovative broadcasting and on-line services provide new forms of entertainment. Many home computers enable a user to balance a checkbook, play video games, or take advantage of home education.

The revolution has brought us to the dawn of a so-called Information Age, whose implications for society are both disturbing and exciting.

THE RISE OF THE INFORMATION AGE

The role of information has increased with the growth of the new technology. The information industry is now the most rapidly increasing segment of the economy. The uses of information technology in all aspects of our lives have accelerated to the point where the 1980s can be called the Information Age. In recent years policymakers have turned more attention to issues related to information. Yet, despite the findings of numerous reports and studies, substantial issues remain unresolved.

In 1977, Porat[3] estimated that about 46 percent of the U.S. workforce was employed in the information industry. This means that more people in the United States are employed in manipulating information than in manufacturing products, providing services, or growing food. The Information Age is thus an "era in which the exchange of information will be as critical a function of economic organization as the production of goods."[4]

One consequence of this transformation is that information is now being valued as a critical resource in the same sense as is labor or capital. Information is different in that it conserves other resources through better decisions,[5] and it often is enhanced rather than depleted through use. Attempts have been made to treat information as a utility, and to describe mechanisms for regulating it.[6] Another approach treats information as a mixture of purely public and private goods, with price reflecting an allocation mechanism rather than a cost-recovery device.[7] Common to all of these approaches is the goal of raising private and public productivity through improved information handling methods.

The emergence of information as a tangible resource has stimulated a vigorous debate concerning its development. Do we need a national policy to manage our information resources? Is it possible to have a single national policy when information transcends so many activities and areas of government? While the recognition of the information economy is relatively recent, these questions have stirred debate in the United States for more than twenty years.

Numerous reports have addressed the issue of scientific and technical information collection and dissemination. Beginning with the so-called "Baker Report,"[8] which recommended the 1958 formation of the Office of Science Information Service within the National Science Foundation, the role of information in research and development began to assume a more prominent position in the context of urgent national goals. In 1963 the reports of Wiesner[9] and Weinberg[10] promulgated the view that government was responsible for disseminating research results, and for maintaining an adequate communications system to promote the commercial applications of those results. Another influential report, the report of the Committee on Scientific and Technical Communication (SATCOM),[11] recommended the participation of private organizations in the nation's information programs, and suggested government support for scientific and technical societies.

In 1972, the "Greenberger Report"[12] expounded a global view of government responsibilities for information dissemination in research, education, and private sector activities. Very much in the spirit of the times, the report championed the government's role in ensuring that the country's information resources were fully utilized for the public good. The report also recognized that centralization of the effort was not a necessity, and that the various public and private organizations engaged in producing and disseminating information were performing adequately, if not optimally.

Much progress has been made toward the goal expressed in these reports: the creation of a communication system for the free flow of scientific and technical information. Many observers nevertheless believe that these overall objectives have not yet been reached, partly because the constituency of users varies significantly, as scientific and technical information concerns merge with broader information policy questions. Throughout recent years, therefore, there has been a steady trend toward broadening the scope of policymaking for information, as seen in the formation of the U.S. National Commission on Libraries and Information Science (1975), the U.S. Domestic Council, Committee on the Right to Privacy (1976), and the U.S. Commission on Federal Paperwork (1977).

Despite these efforts, the tensions continue amongst various players in the federal government, and between the public and private sectors. The absence of clear guidelines and policies regarding information is keenly felt. It can be argued, for example, that the government should ensure the widespread dissemination of socially useful information at the lowest possible cost; on the other hand, some say that the private sector has the more efficient means for doing this. The issue often centers on the definition of unfair competition, especially with respect to the government's funding of information services.

A major reason for the conflict in the development of information policies is the absence of a suitable mechanism for resolving the issues. No distinct roles for the public and private sectors have emerged, and there is no agreement on planning and leadership. The decision-making process within the federal government concerning these questions is accordingly fragmented and disorganized. In response to this situation, there have been many proposals for new national structures to plan and coordinate information activities. Some have suggested that responsibility for the formulation of communications and information policy be centralized, either in a specific department or in the Executive Office of the President, although others contend that improved coordination efforts, together with a recognition that information issues play a large part in national policies, are sufficient to rationalize the decision-making process.

Both the private and the public sectors are deeply involved in generating and using information to manage a society that is increasingly dependent on problem-solving knowledge for a wide diversity of purposes and needs. Clearly, we need to focus more attention on ensuring cooperation both within the government and between the public and private sectors. This issue must be treated as a high priority question as the nation and the world grow increasingly dependent on the availability of information to provide answers to national and international problems.

POLICY QUESTIONS OF THE INFORMATION AGE

The information age has been evolving over a period of at least twenty years, as an economy based on industrial production adapts to one based on the transfer of information. The sheer speed of change is as significant as the changes themselves. The new issues created by the new technology affect all segments of society, and include a broad range of problems, ranging from productivity to privacy to control of information production and manpower requirements.

STRUCTURE OF THE TELECOMMUNICATIONS AND INFORMATION INDUSTRIES

Telecommunications and data processing are merging as a result of the evolution of both technologies and the pressures caused by economic change. The blending of these two economic sectors into the critical component of the information industry is equally dependent on the ability of the technology to support this merger and the economic—and sometimes social—pressures for it.

The heart of the telecommunications network is now a computer—an electronic switch. At the same time, the usefulness of data processing facilities and services is a function of their accessibility through the telecommunications net. The growth markets for telecommunications and data processing exist in merged services such as electronic message systems, electronic funds transfers, and other transaction-oriented offerings.

Telecommunications and data processing borrow techniques from each other to increase the capacity and availability of existing services. Complementing these needs, however, are pressures for new services which could bring about increased efficiency and effectiveness. This second set of motivations is now the primary engine of change. While the reasons for viewing telecommunications and data processing separately appear to be fading, it is not clear that the two industries will be treated as one in policy and legal terms—at least for the foreseeable future. Unresolved policy choices concern regulation, competition, and the assured delivery of services.

Regulatory strategy and requirements for the telecommunications industry are relaxing, but transmission services will remain regulated to a considerable degree, due to several factors. First, the industry is dominated by a corporation of unparalleled size—a circumstance which will not change quickly. Second, the technology employs an increasingly valuable and scarce resource, that is, the electromagnetic spectrum. Third, the industry must operate in conformity with certain powerful social and political policies, such as requirements for the universal availability of service.

A variety of other services will, however, be at least partly deregulated, as a result of Federal Communications Commission decisions, congressional legislation, and state public utility commission actions. This process will affect the so-called "enhanced" telecommunications services, for example, and more participants will be able to enter the market. The challenge for policymakers will be to ensure that the transition is as fair and minimally disruptive as possible, and to support continued technological advancement, rather than restrict it through burdensome regulations. Critical choices will emerge at the points where three distinct portions of the market meet: the regulated data processing and information industries, the newly deregulated enhanced communications services, and the less (but still considerably) regulated transmission services. A key question will be that of how to draw the regulatory line between basic transmission services and enhanced offerings.

INFORMATION OVERLOAD

In the past, the information explosion was largely paper-oriented; today, the new technology is creating huge quantities of computer-readable material. The sheer amount of computer-readable data compounds the traditional problem of sifting useful information from a base of material which is uneven in quality. Reductions in the cost of storing, processing, and retrieving information have only added to this dilemma. The result is that decision-makers are often faced with the increasingly difficult task of selecting critical information from mountains of data.

A case can be made that technology can rationalize the information transfer process, thereby easing information overload. On-line searching, for example, provides improved methods for sorting and selecting needed information from large amounts of data. Systems using computer-based selective dissemination of information, which also highlight materials most closely reflecting a user's interests, eliminate the need to sift through endless computer printouts or printed documents. There is little doubt that as new techniques for data entry emerge—such as direct voice to computer—the amount of data gathered in computer-readable form will continue to increase at a dramatic rate. It is hoped that the technology can also provide the techniques to organize and display information more effectively so that informed decision-making will be enhanced rather than diminished.

PRIVACY

The Federal Privacy Protection Commission carefully emphasized in its 1977 report that information privacy involves more than the traditional concepts of confidentiality imply. Personal privacy in this information society calls for fair practices in maintaining and using information, as well as restrictions on how organizations collect information. The driving force behind the concern for privacy is a desire to protect not only the information about human beings, but also their autonomy and individuality. Contributing to this situation is the drastic reduction in costs for storing information in computers. As offices become highly automated, electronic mail and message systems increase, and personal computers proliferate, the potential for abusing the confidentiality of information grows. Issues of personal privacy reflect another area where policymakers must address the adequacy of existing legal and institutional frameworks to cope with rapid technological advances.

INFORMATION RESOURCE MANAGEMENT

There is a growing awareness that information transfer activities play a critical role in the effective internal management of both public and private sector organizations. As a result, information is increasingly viewed as an important resource to be carefully developed and utilized. In the United States no central authority controls the establishment or maintenance of information systems on a national basis. Recent efforts have been made, however, to coordinate government paperwork activities to reduce redundant collection activities and to increase the sharing of information.

Attention paid to this issue in recent years has grown as the number of databases increases (for example, there were 528 computer-readable, publicly available, bibliographic databases in 1979[13]), the variety of vendors offering information services expands, and the methods for transferring information proliferate. This situation calls for effective coordination and management of all aspects of information gathering, processing, and dissemination activities within an organization to ensure optimal use of data resources.

This changing environment raises a number of policy questions, among them that of better defining the federal government's role in providing public information, in order to prevent conflict and competition between the government and the private sector. Other issues include improving access to vital information, increasing coordination of government information collection and dissemination activities, and designing appropriate management tools and philosophies to improve information resource management.

INFORMATION TECHNOLOGY AND EDUCATION

As the information economy permeates society, there is a growing need for professionals in engineering, programming, and systems analysis beyond the number currently graduating from universities. Many observers believe that our educational institutions themselves should emphasize mathematics and science as preparation for careers in a variety of technological industries. Others contend that the federal government should provide increased funding to foster programs of this kind.

Information technology in education is also receiving renewed attention. Recent advances in miniaturization and telecommunications networks have opened up new ways of assisting students in a wide array of learning environments. They can optimize educational resources which may be geographically dispersed and offer new flexibility in individualized course work. Perhaps most importantly, computer and communications systems will help students to acquire skills for using these technologies throughout their lives and enhance their understanding of modern technologies in general. As the information society becomes more pervasive, the ability to employ automated systems for everything from commercial transactions to home entertainment will become increasingly important.

AVAILABILITY OF INTERNATIONAL TELECOMMUNICATIONS AND INFORMATION RESOURCES

The growth of large scale computer systems and telecommunications networks makes information available all over the world. As the globe continues to shrink, domestic and international activities and policies merge. The United States continues to be the leader in the field of information technology, but is faced with an increasing challenge from its major trading partners.

Of particular concern are some nations' attempts to control the flow of information across their borders. The United States has traditionally supported the concept of free flow of information internationally as fundamental to world economic growth and human rights. Impediments to that flow could substantially damage the U.S. information industry through loss of exports. In the long run, other enterprises that rely heavily on information and communications products and services for efficient international operations will be most significantly harmed. Numerous noneconomic issues—such as national sovereignty, cultural erosion, and personal privacy—are also linked to the international data flow problem. Several nations have responded to this problem by establishing national strategies and policies for information and communications development as well.

Radios are another of several communications resources to raise difficult questions. The radio frequency spectrum and the geostationary earth orbit are finite resources whose use is allocated by the International Telecommunications Union among its 154 members. As the spectrum becomes more congested, issues of equitable allocation of radio frequencies have become increasingly critical as evidenced by the considerable attention focused on the 1979 World Administrative Radio Conference.

These international developments directly affect the ability of the United States to maintain its lead in numerous high technology fields, as well as support the employment of information technology worldwide. It is unclear how the United States should respond and how the interests of domestic users of information technology can be best represented internationally. Other concerns focus on the complementarity of our domestic and international policies in this area and on the benefit at home of harnessing scientific and technical accomplishments abroad.

INFORMATION TECHNOLOGY FORECASTS

To give a sharper edge to the issues raised above, a number of forecasts will be made of specific technological developments in the first half of this decade. These will be divided into products and services emerging from technological advancements, followed by a discussion of possible legislative and regulatory responses.

INFORMATION TECHNOLOGY DEVELOPMENTS

To support the types of information transfer systems described earlier, different computer architectures will be required. Specialists are now developing the technologies needed for that architecture, including:

(1) Hard software, which implements important software functions in specialized chips.
(2) Very large scale integrated circuits (VLSI), which provide the foundation for the changes in technology and computer architectures.
(3) Bus architectures, which link together hardware modules in computer/communications systems via standard interfaces, thus enhancing local area networks.
(4) Extensible languages, which enable the language facility itself rather than traditional libraries to maintain extended functions.

Among the key components of these new architectures will be memory devices and database machines. With new memory devices—such as associative memories—data can be processed without first being transferred from slower memory to fast memory. Database machines approach the ideal of a plug-in database utility. These architectures are particularly important for very large database systems. As noted earlier, the number of databases is continually increasing. Similarly, the number of on-line searches has quadrupled to an estimated 4 million per year since 1975.[14] The market is expected to grow in response to the added value of databases as retrospective literature collections and as more students are exposed to on-line searching. This growth in database services will be possible as a result of two technological developments:

- New network architectures, which will provide superior access to stored information;
- Mini-micro based on-line information retrieval systems.

These will enable end users to subscribe to customized portions of databases and to conduct all searches on an in-house mini-micro system.

These technological forecasts are by no means the only expected developments in information processing in the 1980s, but they are among the most important.

EMERGING INFORMATION SERVICES

The information services which will probably become widespread in the 1980s have, in many cases, already emerged. Several have been referred to earlier in indicating the scope of the communications revolution and the emerging policy issues.

Home Information Systems

Home information services will flourish in the next decade. Several experiments are currently testing consumer response to these systems, generally called teletext and videotex. Using different broadcasting or timesharing approaches, these systems supply information to the home television, and in some cases provide for two-way communication. These systems offer a variety of services, including news, educational programs, and consumer information, and will probably offer more in the future in response to rising customer demand.

Electronic Message Systems

Electronic mail systems are already operating within a growing number of private organizations. At issue is how such services might be made available to the general public. The U.S. Postal Service has developed what it calls Electronic Computer-Originated Mail (ECOM), but it is uncertain whether the Postal Service will be authorized to enter the electronic message business in competition with private sector enterprises. Whatever the outcome of this debate, the technology to accomplish electronic message transmission is readily available and increasingly part of home and office computer systems.

Electronic Publishing

Electronic book and newspaper publishing will flourish in the 1980s. Companies with profitable databases are even now seeking the technology to publish electronically. A number of traditional publishers are expanding to include capabilities for database publishing and delivery of home information services. One trade association estimated that 42 mergers took place in the first half of 1980.[15] This acquisition activity can be expected to continue during the 1980s, as corporate giants respond to the need for new technology.

Office of the Future

The office of the future will begin to take shape in the 1980s as word processing and data processing functions are integrated. Future office managers will be able not only to create local communications networks, but also to transmit large amounts of information over great distances. They will use the newly developed computer-generated graphics to display financial and operational data needed for management reporting and strategic analysis, and thereby enhance their ability for informed decision-making. A related activity in the workplace will be the widespread employment of computer-aided design providing impressive productivity gains.

LEGISLATIVE AND REGULATORY ACTIVITIES

At present, debate among Congress, the courts, the Executive Branch, and the independent regulatory agencies is underway on several key policy questions. The growing complexity of these issues combined with the long-range ramifications of decisions being made requires continued analysis and concern on the part of policymakers. Among the core issues are the following:

(1) *Regulation of the communications industry*. Should AT&T be permitted to offer information and data processing services? If so, under what conditions? What authority should the FCC have for regulating the communications industry? The data processing industry? Is legislation necessary or will anticipated court decisions settle the matter?

(2) *Protection of intellectual property*. Both Congress and the courts are concerned about the effect of automation on traditional legal frameworks for protecting ownership of information. What should be done to adjust copyright provisions to a world of on-line databases and distributing computing systems? What protections should be awarded to software—copyright, patent, or strictly trade secret?

(3) *The role of government in providing information services*. Government and private sector vie as providers of information. What limits should be placed on the government to prevent unfair competition with private sector information providers? How can we improve coordination of public and private sector information needs and services? Should such activities as electronic mail and electronic funds transfer be left to the private sector, without government controls?

(4) *Protection of personal privacy*. Growth of large computer systems and centralized databases will continue to spark concerns for individual privacy. Will Congress pursue additional privacy legislation in such areas as medical or insurance records? Will the greater use of computer systems in administering government programs require concomitant attention to computer systems security and confidentiality of records?

(5) *Government organization of information activities*. This is one area likely to receive increased attention. How can the federal government improve its management of information resources? Is adequate government support being provided for research and development in information technology? In light of barriers to the flow of information being erected around the world, how should the government be organized to represent U.S. information and communications interests internationally?

The positive resolution of these questions during the next several years will require enlightened decision-making. This necessitates a firm understanding of the state of communications and information technologies, of the significant advantages they bring to society, and of the difficult policy issues they raise. A hard look by policymakers at the impact of new technologies on all sectors of the economy and the public is important preparation for the Information Age.

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4 Relations of Science, Government, and Industry: The Case of Recombinant DNA

*Charles Weiner**

INTRODUCTION

The emergence and rapid growth of recombinant DNA and other new techniques for genetic manipulation posed major policy questions in the 1970s and will continue to do so as the research and its applications become increasingly visible in the 1980s. Several of the current issues were vividly highlighted by events during a five-week period in the fall of 1980 in Cambridge, Massachusetts, the center of the public confrontations on the safety of the research that made national headlines in 1976.

On October 14, 1980, a two-day biotechnology symposium opened at the Massachusetts Institute of Technology (MIT) to an overflow audience of 500, mostly from industry and investment companies. The first session featured five distinguished MIT molecular biologists. One of them noted in his introduction that many of the participants had been reading the *Wall Street Journal* that morning because in a few hours shares in a genetic engineering firm (Genentech) were to be offered for the first time on the open stock exchange. The speakers talked about the origins and principles of the basic science involved in recombinant DNA and cell fusion techniques, the frontiers of current research, possible applications, and difficulties that may be inherent to the science itself. Although enthusiastic about new applications, they emphasized that molecular biologists were only just beginning to understand the gene and its expression in higher cells. One urged the assembly of industrialists and potential investors to be careful not to "kill the goose that lays the golden eggs," warning that overly quick exploitation of the research could lower the morale of the scientific community.

At midmorning a speaker interrupted his prepared remarks to announce that the Nobel Prize in Chemistry had just been awarded to three scientists who had developed basic techniques for the new advances in DNA research and applications. At the coffee break, however, the participants were buzzing about another bit of news: The price of the newly offered Genentech stock had more than doubled within the hour. All of this sparked private dispute among several of the speakers about the appropriate relationship of fundamental biological research in the universities to the newly developing biotechnology industries. They were well aware of the issues because all five MIT biologists on the program were involved with commercial enterprises in the field.

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Other dimensions of the new role of biology were brought out by events in Cambridge during the following four weeks. On October 28, the city's Biohazards Committee held a public hearing to gauge community reaction to the plan of Biogen, a major international genetic engineering firm, to establish a Cambridge facility for recombinant DNA research and manufacturing. Within a week, the Cambridge City Council reactivated the Cambridge Experimentation Review Board. This citizens' group had been created in 1976 to consider whether recombinant DNA research at Harvard and MIT posed a threat to the community, and had gone out of existence in early 1977 after recommending what was to become the nation's first local ordinance regulating such research. In 1980, the Council reconvened the board to consider Biogen's request to locate in the city. Two weeks later, in the city of Waltham (part of the Route 128 high technology industrial area near Cambridge), the city council held a public hearing on similar issues related to the operation of a Waltham genetic engineering firm, Collaborative Genetics. In December 1980, Waltham approved an ordinance regulating recombinant DNA experimentation and use in the city. The ordinance requires such work to be done under the National Institutes of Health (NIH) guidelines and mandates some additional safety measures.

Meanwhile, a newly founded company, Genetics Institute, sought permission to establish its laboratory in Somerville, immediately adjacent to Cambridge. In January 1981, negative community response was expressed at a hearing attended by more than 100 people. One Somerville alderman challenged the credibility of a leading Harvard biologist as a safety expert because of his major role in the firm: "You're more than a scientist now. You're a businessman."[1] Harvard and MIT biologists are prominently involved in the three genetic engineering companies under public scrutiny by local governments in Cambridge, Somerville, and Waltham.

Yet another indication of current reactions to issues raised by the applications of molecular genetics was the response by the faculty of Harvard University to the proposal that the university itself take a role in founding a company for commercial exploitation of recombinant DNA techniques, involving some faculty members and making use of university-owned patents. The intense discussions in Cambridge had echoes at other leading universities throughout the United States. Finally, in November 1980, the Harvard Corporation rejected the plan because of its potential for generating conflicts with academic values through interference with open communication, influence on criteria for promotion, intrusion on commitments to teaching and research, and damage to the credibility and integrity of the university.[2] Harvard (and many other American universities) continue, however, to explore ways of obtaining financial benefit from the applications of publicly funded research done in university laboratories.

These developments dramatically illustrate major unresolved national issues in contemporary relations among science, government, and industry. Although the focus in this account is on recombinant DNA technology, similar issues arise in other areas of science and engineering. The problems involve:

(1) The public's perception of new technology and determination of the role the public should play in defining the purposes and goals of new technology, and the conditions under which it should be developed;
(2) Determination of whether and how to regulate new technology;
(3) The relationship of federally funded basic research to commercial exploitation of its applications;
(4) The effects of increased university interaction with industry on the direction and quality of basic science, on the community of scientists, and on the university environment.

In addition, ethical issues stemming from the applications of genetics will be increasingly important in the 1980s, at the level of practical reality rather than mere abstraction.

This paper reviews the background and current status of these issues in relation to recombinant DNA techniques. Because much has already been written about them, I will emphasize only those issues that have not yet received adequate attention (see the bibliography which follows this paper). The field and the policy issues are unfolding before our eyes, providing an opportunity for close observation of the social and intellectual processes of the growth of knowledge and its uses, and emphasizing the need for critical examination of the related policy processes.

GROWTH OF DNA RESEARCH AND CONCERN ABOUT RISKS IN THE 1970s

The development of recombinant DNA techniques in the early 1970s was a major event in the history of science and was a result of decades of fruitful research in molecular biology in several nations. These techniques involved the use of newly discovered restriction enzymes to isolate and remove specific gene sequences from DNA molecules of various organisms, and to recombine them with the DNA of other organisms. These techniques also involved the application of methods to reproduce large amounts of exact copies (clones) of the hybrid or recombinant DNA molecules. The ability to manipulate nucleotide sequences directly made it possible to transmit genetic information among different species. It provided a powerful new tool for study of the structure and function of genes and made it possible to study details of DNA and its transcription in cells of higher organisms. Biologists immediately recognized the major significance of these developments. They were now able to solve problems at the forefront of knowledge, which also had possible important applications.

Of comparable importance was the fact that the scientists involved in the work made an unprecedented effort to inform the scientific community—and, indirectly, the public—not only of the exciting new advances and potential benefits of their basic research, but also of their concern about potential hazards in their own laboratory work. The extraordinary extent of these concerns was made visible in 1974 when these researchers called on fellow scientists to refrain voluntarily from doing certain experiments until their hazards were assessed and safeguards devised. From the start, throughout the February 1975 Asilomar conference, and during subsequent efforts to develop guidelines, the issue was defined by the scientists as a limited problem that the scientific community could solve by technical means. Possible abuse or misuse of the research was mentioned occasionally, but it was excluded from major consideration, as were also its social implications. The discussions focused on whether there was any danger in the research, and if so, how the danger could be avoided while the research continued.[3]

Scientists, sensing the excitement and popularity of the new field, were eager to do recombinant DNA research. Developers of the guidelines, convinced the field should be allowed to grow, were reluctant to impose artificial restraints. The National Institutes of Health were thus in the ambiguous position of encouraging the growth of research using recombinant DNA techniques while at the same time taking responsibility for establishing and enforcing safety regulations restricting such research. Concurrently, scientists were tooling up to use the new techniques and were waiting for the green light to proceed as rapidly as possible. Many of those charged with developing guidelines felt that, even though they lacked information, they had to move as quickly as possible.

The scientists involved believed that they needed to demonstrate that scientists, on their own, could act responsibly to protect the public. They felt that if they didn't do it on their own, someone else would do it for them. When pressures concerning regulation exist from both scientists and the public and a large degree of uncertainty prevails, there is bound to be disagreement on the scientific basis of risks and the weight attached to them. The process of establishing rules therefore involved formulating a series of compromises. It was necessary to provide a framework for safe conduct of the research acceptable to the scientists affected by the regulations and at the same time to assure the public that it would be protected against possible hazards. The NIH Guidelines for Research Involving Recombinant DNA Molecules took effect in July 1976, and subsequently governed federally funded university research in the United States. They became the model for guidelines in several other countries as well.

By 1977, scientists in the field were issuing public statements explaining that they now felt that the hazards had been exaggerated and that, in fact, the experience of biologists since 1973 (when they first sounded the alarm) had convinced them that much of the concern was groundless. These statements came after a year of public controversy regarding the risks involved, and after Congress had begun to consider legislation to regulate recombinant DNA research. The experience of the biologists since 1973 had been political as well as scientific.

Public interest had been relatively limited until 1976. Then, as research began, concern surfaced in several academic communities. Some public controversy was sparked by scientists who were critical of the guidelines on scientific grounds. But many nonscientists quickly realized that the information essential for evaluating potential mishaps (and thus, the adequacy of the guidelines) was not available. There were many unknowns. Were the guidelines adequate? Were they to be believed as a matter of faith? Which scientists should be trusted under such circumstances? Were scientists acting out of self-interest when they assured the public that research was safe? What public health benefits might be delayed or lost by slowing down the research until more was known about the risks?

By the end of 1977, 16 bills were introduced in Congress and the subject was widely probed in 25 hearings. At first, many scientists were prepared to accept the inevitability of federal legislation, which they hoped would extend NIH guidelines governing academic research to industry and prevent the proliferation of local regulations more severe than the guidelines. They soon mobilized vociferous opposition to legislation that they feared would be too rigid for a new field in which the perceptions of risk were changing rapidly. They believed that such legislation would restrict their research and threaten their relative autonomy. In their lobbying efforts the scientists argued that new scientific evidence and analysis of existing data demonstrated that the probability of risk from recombinant DNA experiments was much lower than they had originally thought. Sympathetic media coverage and increasing references to impending medical benefits of the research contributed to a changed congressional mood. None of the pending bills came to a vote.

Rapid growth of the research and its applications occurred despite the public disputes, restricting guidelines, special containment facilities, and related bureaucratic impediments that reached down to the laboratory level. While the regulatory issues were being debated in committees and in public hearings during the late 1970s, the laboratory use of recombinant DNA techniques was booming, as its potential was being explored in one subfield of biology after another. It became a central tool for research which previously had been considered impractical or impossible. Combined with other new developments, such as rapid methods of DNA sequencing, it has created great intellectual excitement and activity affecting all of biology, including cell biology and immunology. Already the research has led to a dramatic change in the understanding of the structure of genes through the discovery of intervening sequences and greater understanding of transposable elements.[4] Recombinant DNA methodology rapidly has become a required technique in molecular biology laboratories, and more and more scientists are using this powerful approach because of its simplicity, its effectiveness, and its fruitfulness in opening new areas of research. The increase in the number of federal grants, the emergence of new journals and newsletters, special conferences, and training workshops devoted to recombinant DNA research all indicate the enormous growth of research in the field.[5]

Although potential applications were clear from the beginning, they became more apparent as the research progressed, and developed much more rapidly than had been anticipated. Recombinant DNA and gene sequencing techniques have made it possible not only to isolate and analyze genes but also to engineer genes to make specific proteins for synthesis of such substances as insulin, somatostatin, interferon, and other polypeptides with important biomedical application. In addition to pharmaceutical and medical applications, the use of the technique in producing industrially useful enzymes has also sparked great interest, and activities are underway in the agricultural, chemical, and energy areas. By 1980 an estimated 100 U.S. companies were evaluating or conducting recombinant DNA or other biotechnology research.[6]

On balance, it may well be that concern and controversy over risks and the need for control of research have accelerated growth of the field rather than retarded it. This hypothesis needs further study, but it is supported by several consequences of the special treatment given to recombinant DNA research. From the beginning, a need was perceived to assess the nature and potential of the research in order to determine whether it posed risks and, if so, to devise methods to reduce and contain them. This led to acceleration and supplementation of normal channels of scientific communication. Highly publicized meetings such as Asilomar in 1975 acquainted many scientists with the background of the research and with the newest results considerably earlier than they otherwise would have learned of it. The development of guidelines, the establishment in 1976 of the NIH Office of Recombinant DNA Activities, which distributed information on safe and efficient host-vector systems for research, and the publication of a newsletter were among the institutional efforts that stimulated the informal communication network in the budding field and enlarged its scope.

In addition, the discussions of the risks and benefits of the research in public forums, hearings, and the media stimulated interest among investors, industrialists, and scientists in the possible applications. A number of biologists never before involved in applied research began to consider commercial uses of their work. In some instances, the early results of such efforts to produce substances with important human medical applications were reported directly to the press and to congressional committees engaged in legislative hearings even before they were published in scientific journals, in order to bolster the argument that the benefits side of the research outweighed the risks.

All of these activities contributed to the growth of a technique which had great scientific merit from its inception because it had strong intellectual appeal, provided fruitful opportunities for research and publication, and was relatively easy to learn and do. Some experiments and some applications, however, were temporarily delayed because of the time involved in the process of establishing, revising, and interpreting safety guidelines. In addition, some scientists in the field had less time for research because of their participation in committee meetings and public hearings and because of the increased paperwork related to their laboratories. The overall cost of the research was increased by the guidelines and risk assessment activities and by the expenses for new containment facilities, many of which are now no longer required because of changes in the guidelines. Funds for risk assignment and new facilities usually came from budget categories designated for evaluation or building and did not drain funds available for research. On the whole, these delays, distractions, and costs appear to have been more than offset by the acceleration of the field caused by the extraordinary diffusion of information and the intrinsic appeal of the research.

CURRENT STATUS OF DNA TECHNOLOGY AND ITS REGULATION

What is the status of regulation, risk assessment, and public perception and involvement in recombinant DNA technology at the beginning of the 1980s?

REGULATION

The NIH guidelines are the only regulations specifically applying to recombinant DNA research. They have been adopted by other federal agencies and now are mandatory for all federally funded research. Noncompliance can result in withdrawal of funding from the institution. Primary responsibility for determining that experiments are carried out in accordance with the guidelines is assigned to the Institutional Biosafety Committee (IBC) at the institution where the research is done. The guidelines have undergone three major revisions by the NIH Recombinant DNA Advisory Committee (RAC) since 1976 and are continually subject to revision. The trend has been to relax physical and biological containment standards and accountability protocols. At present, about 90 percent of recombinant DNA work being pursued in the United States is either no longer covered by the guidelines or is subject to only minimal controls equivalent to "standard laboratory practice." In most cases researchers do not need to use the safety systems that had been introduced for biological and physical containment under the original guidelines. NIH further reduced its oversight role in November 1980 by eliminating the requirement for researchers to register and receive NIH approval before initiating experiments for which the guidelines already specify the containment level. This responsibility is now in the hands of the IBC at the institution where the work is to be done.[7]

NIH has not yet studied the effectiveness of the IBCs but plans to do so. When the heads of the IBCs from almost 200 institutions met in Washington late in November 1980, many balked at the added responsibility of such an evaluation. Many participants believed that the IBCs could not be justified exclusively on the basis of the potential risks of recombinant DNA research. They believed that such research posed no greater hazards than identifiable biohazards in other fields.[8]

With the proliferation of industrial activity in the field and in the absence of federal legislation, NIH has developed procedures for voluntary compliance with the guidelines by industries using recombinant DNA techniques, and most if not all of the companies have announced that they will comply. The NIH Recombinant DNA Advisory Committee is currently debating its role in regulating industry through voluntary compliance. Many members and outside observers have challenged the ability of the committee to make judgments and take responsibility regarding industrial practices where they have inadequate expertise to deal with large-scale fermentation processes and no authority to monitor or enforce compliance with the guidelines. The trend has been for the committee to recommend reduction of its responsibilities for the safety of research in the private sector, even in the absence of evidence that the regulatory agencies are playing an active role in the field.

Several federal agencies are currently considering their roles and are participating in the industrial practices subcommittee of the Federal Interagency Advisory Committee on Recombinant DNA Research, and a few are beginning limited efforts at regulation. The Food and Drug Administration is in the final stage of defining the policy process to regulate drugs produced by recombinant DNA techniques. The National Institute for Occupational Safety and Health has initiated a series of onsite surveys of companies starting up large-scale recombinant DNA work and is studying appropriate recommendations to industry for medical surveillance of employees. The Environmental Protection Agency has established a research program to provide a data base on the environmental impacts of large-scale genetic engineering, including studies of the establishment and persistence of novel genomes in a variety of environments, modeling of the probability of escape of organisms from containment, and exchange of genetic information.

In addition, the Office of Technology Assessment has completed a study called *Impacts of Applied Genetics: Microorganisms, Plants, and Animals,* which reviews several aspects of the subject, including current regulatory activities, and formulates options for congressional action. A Senate oversight hearing on industrial applications of recombinant DNA techniques was held in May 1980, and, although a bill (S. 2234) to register all recombinant DNA research with the Department of Health and Human Services was introduced earlier in the year, it remained in committee and no further action was taken by the end of the 96th Congress.[9] There is little evidence of widespread congressional support for special regulation in this field.

RISK ASSESSMENT

Potential safety risks of recombinant DNA research have been the focus of concern since the early 1970s. In 1977 and 1978 a consensus emerged among researchers in the field that the potential risks were less serious than had been originally feared. Upon more reflective analysis of existing data, these biologists became convinced that most of their original concerns were unfounded. At conferences and workshops in 1977 and 1978, efforts were made to assess risks on the basis of available knowledge. The results were reassuring to the scientists and encouraged them to relax the guidelines.

At that time, however, the first experiments specifically designed to assess risks in this field were just getting under way. Defining experiments to assess risks in a rapidly changing new field had inherent difficulties, and efforts of this kind lacked precedent and experience.[10] Risk assessments had been further delayed by lack of interest among scientists and bureaucratic obstacles. Some of the biologists involved in the development of NIH guidelines maintain that risk assessment was undertaken reluctantly, in response to political pressure, rather than wholeheartedly, in response to technological reasoning.

Others argue that, although some questions have been answered, there is still too much uncertainty and not enough systematic knowledge of risk assessment. Several thoughtful risk assessment experiments have focused on specific areas where information was needed. Although these experiments have laid to rest a number of the concerns that had been raised, some researchers in the field and some scientists on the RAC feel that the interpretation of data from these experiments has been overly optimistic and that problems and ambiguities noted by the investigators have been overlooked or unduly minimized. In some cases, they argue, generalizations have been prematurely made at a stage when scientific knowledge and prudence call for further case-by-case analysis. They maintain that too few risk experiments have been done and warn against premature abandonment of risk assessment.[11]

The development and annual update by NIH of a comprehensive risk assessment program was mandated by the Secretary of the Department of Health, Education and Welfare when the revised NIH guidelines were issued in December 1978. It was not until late 1979 that NIH, the agency responsible for both the promotion and regulation of the research, published the final version of the first plan. The NIH proposal for the first annual update of the plan was released for public comment in September 1980, and the final version of the revised risk assessment program will be announced in mid-1981.[12]

The hazards of recombinant DNA research remain hypothetical after five years of intense research conducted under safety guidelines at laboratories throughout the world. The new knowledge gained from the research, the promise of its applications, and the absence thus far of demonstrated risk, have all contributed to a lack of enthusiasm among researchers for vigorous risk assessment. Now that some political battles have been won and the public mood seems favorable, much of the will to devise and conduct risk studies has disappeared. Researchers who have lingering doubts about the safety of specific experiments or the adequacy of the containment prescribed by guidelines are reluctant to discuss them publicly because they do not want to be labeled as dissidents or to unleash new negative public reactions. Some researchers are critical of those scientists who, in their eagerness to reassure the public, rashly proclaim that the research is perfectly safe. These enthusiasts, some argue, may provoke a backlash if there is a real (or perceived) mishap. The very success of recombinant DNA research in yielding knowledge about genetic structure has had a sobering effect on many scientists, who realize that the field is full of surprises.

At the same time there is apprehension that large-scale industrial operations might pose special problems for risk assessment. In some communities, continuing doubts about the safety of recombinant DNA research have been coupled with suspicions about the responsibility of industry generally, especially in the wake of increasing public awareness of occupational safety and industrial toxic waste problems. The motives of scientists who offer reassurance have also been questioned because of their assumed financial stake in the outcome. Federal and state regulatory agencies have done little to address these local concerns because they are reluctant to step in when no risk has been demonstrated and they lack the appropriate expertise to assess risk themselves.[13]

PUBLIC INVOLVEMENT

By now it has become clear that the question is not whether the public should participate in scientific and technological affairs that have important social consequences, but how they can participate effectively and intelligently. Despite high public interest in the new developments in molecular genetics, opportunities for public participation at the decision-making level are still limited and participation is often ineffective. Opportunities for public input at the 1976 and 1977 NIH hearings on the guidelines created some channels for public comment, and NIH has published an extensive record of the guidelines process.[14] More recently, the public has shown little interest in the guidelines on the national level, and the media have only sparsely covered them, except when they have been reportedly violated by researchers.

Several positions on the NIH Recombinant DNA Advisory Committee have been designated for "public members" (about one-third of the present members, including the chairman, are not scientists). Their participation has introduced some policy issues that otherwise might not have been raised.[15] Yet most of the issues placed before the committee are technical and generally beyond the expertise of members not trained in the relevant scientific fields. Many of the scientists on the committee have made special efforts to explain technical matters to nonscientist members. Several of the nonscientists have developed considerable ability to discuss many of the technical issues. Dissenting views on matters of procedure and values—most recently regarding industrial applications—have been regularly advanced by several public members, but they comprise a relatively isolated minority on the committee and generally have been heavily outvoted. The public members have not tended to vote as a bloc. Although the committee's meetings are open to the public, most of the observers who have attended during the past several years have been representatives of industrial firms with interests in the field.[16]

A few groups, such as the Cambridge Experimentation Review Board, have been founded, but they have been short-lived and have not been evaluated fully.[17] They were initiated on short notice in response to a crisis and never developed a continuing involvement of the public. The reactivated Cambridge board, whose membership was virtually the same as that of the original board of 1976, was able to build on its past experience and function more effectively. In assessing the adequacy of regulation of industrial recombinant DNA activities, the board consulted its own experts from a variety of relevant fields, including authorities on fermentation processes and sewage disposal.

APPLIED MOLECULAR GENETICS IN THE 1980s: POLICY PROSPECTS AND PROBLEMS

PUBLIC EXPECTATIONS

As the public controversy over the risks subsided in the late 1970s, attention focused on the benefits of the research. In 1980, a steady stream of enthusiastic accounts in the scientific, business, and popular press, and a number of workshops and conferences hailed a revolution in molecular genetics and the birth of the Age of Biotechnology.[18] This exuberant response was based not only on the power of recombinant DNA technology, but also on its appeal as an embodiment of current values. Recombinant DNA is presented as a panacea that will increase productivity and profit, help solve the energy problem, increase world food production, and improve the public health. It is also regarded as consistent with the need for protection of the environment and conservation of resources. The new genetic technology is promoted as a "tech fix" for lagging rates of economic growth and productivity. For those seeking solutions to economic problems through technological innovation and transfer, recombinant DNA techniques represent ideal examples of successful experiments in this direction. Some academic institutions advance similar arguments in the hope that applications of genetic research developed in university laboratories can provide them with needed income.

The enthusiasm also reflects the desire to demonstrate to the public that the research has beneficial applications and to discourage unwarranted fears that might needlessly delay bringing needed products on the market. In addition, recombinant DNA technology is offered as a dramatic example of the ultimate payoff of basic research. Government policy has been based on the assumption that even basic science research should pay off if it is to receive public funds. Historically, this assumption has led to pressure on scientists for visible and immediate results. The clear potential of biomedical research to alleviate human suffering places it under special pressure. The history of the relationships among Congress, NIH, NSF, and other executive agencies in the past two decades demonstrates that the political environment significantly influences the establishment of research priorities, tending to favor areas such as cancer research that may yield results of current national interest.[19]

The new industry of genetic technology hopes to develop, manufacture, and profitably market needed products through the exploitation of state-of-the-art genetic engineering techniques. Although the prospects appear promising, the technology is largely untried and the scientific understanding basic to it is largely incomplete. The effectiveness, safety, and economic advantage of the products have yet to be demonstrated. Early publicity about human therapeutic substances, such as human insulin, growth hormones, and interferon—all produced using recombinant DNA techniques—has not always made clear whether the gene product was biologically active and performed the same functions that it would perform naturally.[20] The genetic technology industry must purify its products to separate them from unwanted or unsafe substances that might be produced by the bacterium containing the recombinant DNA molecule, and all of this has to be economically feasible. Because tests are necessary to establish the safety and efficacy of the substances, there may be considerable time between laboratory research and commercial availability. Competition in the biotechnology industry is hastening the pace, however: a few companies have already started human testing of bacterial insulin, growth hormone, and interferon.

In raising hopes of solutions to major health problems, the genetic technology industry may be overselling the public on the new technologies. For example, magazines and newspapers have already described interferon as a cancer cure. Natural human optimism is in this situation exacerbated by the highly competitive nature of the industry, the prospect of large profits, the predictable enthusiasm of pioneers opening up new fields, the proliferation of new companies with a need to attract investors in order to get off the ground, and the idealization of this new technology as a solution to economic, social, and health problems. Unfulfilled expectations might well lead the public to doubt the credibility and motives of scientists, and to become disappointed and impatient with the pace and direction of research. Discontent might also develop among young scientists recruited into the genetic technology industry if the prospects for career development and continuity do not materialize in what originally appeared to be a glamorous, intellectually stimulating, and lucrative field.

Just as it would be irresponsible to overstate the claims for the new genetic technology industry, so would it be unsound to encourage and facilitate its growth without careful consideration of important unresolved policy issues concerning the relations of science, government, and industry.

PATENTING OF LIVING ORGANISMS

The June 1980 Supreme Court decision (five votes to four) permitting the patenting of "a live human-made micro-organism" opened the door to action on more than 100 patent applications based on recombinant DNA techniques. The majority opinion of the court took the position that the distinction between living and nonliving things was not relevant to the granting of a patent, and that the criteria for issuing a patent must rest on whether the genetically manipulated bacterial strain was "a product of human ingenuity" or "a product of nature." This opinion rested on interpretation of the intent of Congress as expressed in the Patent Act of 1790 (embodied in 35 U.S.C. Section 101), the 1930 Plant Patent Act, and the 1970 Plant Variety Protection Act. The court stated that Congress should debate this question if it disagreed with the ruling. The dissenting opinion held that Congress had not foreseen the new areas made possible by genetic engineering and argued that Congress must act before the court could extend patent rights into such areas.[21]

The decision received wide press coverage and stimulated discussions about the ethical implications of private ownership of life forms. The impact of the decision on the genetic engineering industry and on the free flow of scientific information was also considered. The Supreme Court said its decision rested on a narrow interpretation of patent law, and some observers subsequently argued that the ruling did not involve important larger issues of public policy. Others maintained that the court was indicating that the legal basis for its decision was inadequate and was inviting public bodies to prepare and discuss legislation.[22] Congress can, of course, enact legislation to prohibit patenting of living organisms, whether they are modified or not, or it can specifically provide for patents of living organisms to whatever extent it sees fit. Congressional hearings may be held on the subject during 1981, and the President's Commission for the Study of Ethical Problems in Medicine and Biomedical and Behavioral Research is examining the issue as part of a more general study on genetic engineering to be completed in 1981. A "Public Forum on Patentability of Microorganisms" was held in July 1980 by the American Society for Microbiology and the House Committee on Science and Technology, but there has as yet been no other visible activity in Washington.

Public interest in this issue is high, and additional opportunity should be provided for public discussion of appropriate ways to deal with the development, ownership, and use of living organisms. Questions that have not been adequately considered are:

- What effect will patenting have on the overall development of biomedical research? Does genetic research have special problems not shared by other fields? What can be learned from the history of the effect of patents in other areas of research?

- Who should profit from commercial applications of publicly funded research? Private industry? Scientists whose research yielded the applications? The academic institutions which sponsored the research? The citizens whose tax dollars supported the research?

- What ethical considerations should be taken into account when deciding patent policy? How can effective public input be obtained and what role will it have in the formulation of policy?

Many scientists are deeply concerned about the threat which commercial interests may pose to the traditional free exchange of data and to open publication in scientific journals. Peer review, verification of results, and ultimately the growth of knowledge are not possible when research procedures are kept secret for commercial reasons. Even though the patent laws require considerable disclosures, many scientists are concerned that the rapid industrialization of newly spawned basic research will skew the intellectual development of the field and will degrade cooperation within the scientific community. Even before the Supreme Court decision, academic biology departments were disturbed by the possibility of commercial gain, which sparked disputes among colleagues, aroused suspicions of piracy and premature publication, and interfered with the exchange of data, bacterial strains, and cell lines.[23]

Stanford, Harvard, Yale, and the University of Michigan are only some of the universities investigating ways to retain an interest in potentially profitable patents. These institutions are, by and large, responding to increasing involvement of university biologists with private companies, either as consultants or founders and part owners. Individual scientists are voicing their concern about the effect of commercial interests on their field or on their institutions, in private discussions or through group letters circulated among their colleagues. Yet the scientific community and the public have had little opportunity to discuss these issues systematically. Assessment of the effect of existing arrangements on the university, on the health of science, on industry, and on the public has, to date, been inadequate.

THE HEALTH OF SCIENCE

The recombinant DNA case directly involves three major factors that contribute to the health of science: the strength of the universities, financial support for basic research, and the social system of the related scientific community.

Major research universities, where most of the work in basic science has traditionally been done, increasingly complain of impending financial shortfalls because of the steadily rising costs for plant, equipment, and personnel, especially for costs associated with scientific research. For several years, university administrators have warned that federal support is not keeping pace with the increase in operating expenses required to maintain high standards of research. In addition, federal support for basic research is decreasing (in constant dollars) in some fields. Government agencies that traditionally have supported all or most basic research in certain fields are increasingly under pressure to emphasize practical results and many are trying to hasten the transfer of scientific knowledge to practical technology.

Influenced by the commercial applications of DNA techniques, a number of university researchers, not previously involved with industry, have become industrial consultants, joined industrial laboratories, or taken leading roles in founding new companies. The research on which the applications are based was developed primarily in university laboratories supported by public funds. In past attempts to reap some of the financial benefits from new developments, major universities developed a variety of arrangements to benefit from the ownership and licensing of patents. (For example, the Wisconsin Alumni Research Foundation was established in 1925.) Several universities are currently discussing other arrangements to retain a portion of the profits generated from university research.

The proposal recently advanced by the administration of Harvard University provoked strong objections from its own faculty and was withdrawn, but the issue at Harvard is by no means settled. The proposed Harvard experiment suggested major revision of the university patent policy and alteration of the formal relationships of the university to its investments, and of the faculty to industry. It would have involved the university and some of its biology faculty in founding a genetic engineering company in which both the faculty members and the university would be shareholders, along with private venture capital investors. The university, as owner of any patents resulting from the work in a professor's laboratory, would license use of those patents to the company. At one point in the discussions, the Harvard administration proposed that space in a new biochemistry and molecular biology building be used as temporary quarters for the company.[24]

The reaction of the faculty, first in the biology department and then throughout the entire university, was overwhelmingly negative. The proposal was discussed at faculty and department meetings and in group letters circulated within the university. It stimulated comments in the national press.[25] Despite the university's claim that there would be safeguards to prevent abuse of the system, opponents argued that major university investment in the commercial work of faculty members would compromise academic freedom and lead to unavoidable conflicts of interest, to the detriment of the research and educational responsibilities of the faculty and the university. Ultimately, the Harvard Corporation, stating that "academic risks outweighed the financial gain," voted to withdraw the proposal.[26] Explaining the decision, President Bok cited several of the objections that had been raised, including (a) that academic discussion could be impaired because of commercial competition; (b) that professors and graduate students might shirk academic duties and interests to pursue commercial ones; (c) that the administration's authority to protect its academic interests might diminish; and (d) that Harvard's reputation for academic integrity might be damaged by even the appearance of conflict between its academic and financial interests. The university administration emphasized, however, that it badly needed additional sources of funding to strengthen the university's teaching and research and that it would continue to explore similar proposals.[27]

For several years, Congress has discussed the appropriate relationship of the university to commercial exploitation of federally funded research done on university premises. Several recent congressional actions focus on transfer of technology and university licensing of patents and will probably stimulate great interest in the near future. Congress has not, however, adequately considered the need to provide stable and increasing support for basic research. Nor has Congress recognized the importance of protecting the university from damaging pressures that would impair the quality of research and inhibit open communication among scientists.

These problems were stressed in November 1980 when a group of recent Nobel Prize winners visited the House Subcommittee on Science, Research, and Technology to appeal for more funds for basic research and for greater congressional sensitivity to the special problems of the scientific community. On this occasion, Hamilton Smith, the microbiologist who shared the Nobel Prize in 1978 for work that laid the foundations for recombinant DNA research, expressed his concern that the rush toward commercial applications in biology would harm the academic environment which has nurtured basic research. Smith noted that "free exchange of scientific information. . . may suffer, and long-term progress may be traded for short-term financial gain. . . . We still do not know the structure of human chromosomes, how the genes are arranged, how tissues and organs are formed, or even how any single human gene is regulated and expressed." Smith called for increased federal support of such academic research to "prevent the gutting of the university faculty" by new companies in the field.[28]

An earlier warning had been sent to Congress in 1978 by another Nobel laureate in biology, Joshua Lederberg, who predicted, "The possibility of profit—especially when other funding is so tight—will be a distorting influence on open communication and on the pursuit of scholarship."[29] Lederberg wrote that he did not think that his views were widely shared within the universities. In 1981, however, these problems have developed into a major concern.

University scientists in some fields of physics, chemistry, and biology have long been involved with commercial applications of their research, especially since the end of World War II. However, there has been little systematic evaluation or historical analysis of the effects of these experiences on the university, on the research environment, on the direction and quality of basic science, or on the scientists themselves. Understanding of these effects—and how they have differed for specific scientific disciplines (and groups within them), institutions, and historical periods—will be especially helpful in assessing and responding to the rapid changes now underway in molecular genetics.

The events of the past decade—the development of powerful new research techniques, the demands for increased public scrutiny of the procedures and goals of basic research in molecular biology, and the new relevance of such research for industrial and biomedical applications—have had profound effects on the community of researchers involved. The excitement of these scientists over the possibility of opening up new frontiers was coupled with concern that safety problems and public distrust might hamper the research. The regulatory procedures, public confrontation, and political battles were new and unexpected, and the rapid growth of opportunities for commercial applications of their work raised new dilemmas. Solutions to the current problems must take into account the effects on the health of the scientific community.

SOCIAL AND ETHICAL CONSEQUENCES

The enormous potential of genetic technology in a variety of fields has been much heralded. Even if only some of the hopes of its promoters materialize, the new technology will surely transform our lives in the next decades. Despite the highly visible, adverse effects of technology in recent times, there has been little public discussion of the potential economic, social, and environmental consequences of new technologies, nor has there been debate on desirable priorities for application. (Belatedly, energy technologies are now under debate.) Biotechnology presents an opportunity for just such constructive discussion and planning. Which applications are socially valued? Which may be undesirable? What would we like the technology to do? Does it automatically serve "human needs" and "public purposes?" Who should decide about its uses, and who will benefit from it? Can we in good conscience introduce and encourage the growth of a powerful new technology without asking why we are doing it and for whom?

More than a decade ago the influential technology assessment report of the National Academy of Sciences (NAS) emphasized the need to pose such questions at an early stage in the development of new technology. The NAS report stressed that, in decision-making on technology, a wide range of human values and concerns should be considered, policy options should be preserved, and efforts to reduce uncertainties should precede or accompany decisions. The report called for favoring technological projects or developments that leave maximum room for maneuver and noted that "the reversibility of an action should thus be counted as a major benefit; its irreversibility, a major cost." It also called for limits "on the extent to which *any* major technology is allowed to proliferate (or conversely, to stagnate) without the gathering of fairly definite evidence, either by the developers themselves or by some public agency, as to the character and extent of possible harmful effects." The NAS committee also warned that "society simply cannot afford to assume that the harmful consequences of prevalent technological trends will be negligible or will prove readily correctable when they appear."[30]

In the case of the biotechnology industry, the concern about possible biohazards appears to have diverted the attention of scientists and policymakers during the late 1970s from the need and the opportunity to make such public assessments while the commercial applications were rapidly developing. Federal efforts were initially focused primarily on human health risks. Studies on the broader issues were initiated late and are of limited scale and scope. The Environmental Protection Agency has contracted for a study to produce an assessment of "the potential ecologic, economic and social impact" of the applied genetics industry, which is expected to be completed in 1982. The Office of Technology Assessment study, completed in January 1981, covers a number of related issues but is not yet available for public discussion. A Congressional Research Service report on biotechnology prepared for the Subcommittee on Science, Research, and Technology of the House Committee on Science and Technology has recently become available.[31] It provides a useful overview which could help stimulate needed public discussion of the aims, directions, priorities, and potential social and ethical impacts of the development of biotechnology.

Although there are ethical dimensions of all of the issues discussed thus far, several ethical problems related to genetic research and its applications have been of special interest. Recombinant DNA, along with other new techniques such as rapid gene sequencing, cell fusion, and mass tissue culture methods, may be applied to higher organisms, including humans. There is public concern about the ethical aspects of human genetic screening, amniocentesis, and, more recently, *in-vitro* fertilization, and gene therapy. The potential long-term effects of applied genetics on the environment and on evolution have also been discussed in terms of ethical responsibilities. As a result of the Supreme Court patent decision, additional concern about the ethical implications of private ownership of living organisms has been voiced by many individuals and groups, including the National Council of Churches.[32]

Recent accounts in the scientific and popular press have called attention to the ethical decisions university biologists are now facing because of possible conflicts of interest arising from their involvement with industry.

Reports of demonstrated or alleged violations of the NIH guidelines by a few researchers have also highlighted the ethical problems encountered under a system of self-regulation where the principal investigator has primary responsibility for ensuring that safe experimental procedures are followed.[33]

The interest in these issues among the public and within the scientific community provides an opportunity for serious, positive discussion. Biologists have a good record of concern about the ethical aspects of their work. Many biologists recognize that their work touches on deep human values and has important effects on society. Because of their special knowledge they can anticipate and identify possible problems related to their work at an early stage, and participate with other groups to help make choices in accordance with publicly discussed ethical and value systems. Many of the leading genetic researchers have stated their awareness of the need to help initiate public discussion of such issues when the time seems appropriate. To establish and maintain public confidence in their credibility and social responsibility, scientists must be among the first to speak out. However, some scientists denigrate those who first warned against potential hazards of DNA research. In addition, several of the biologists who originally expressed concern have publicly recanted. Attitudes of this kind may discourage younger colleagues from exercising their responsibilities as scientists.

Biologists in the 1980s face issues that pose special problems for their own professional roles, for ethical standards, and for their relationships to the public. A vigorous effort should be made to encourage working scientists to consider these problems. Studies are needed of the aspects of the life of science and the social system of science that encourage or inhibit a scientist to develop an awareness of the ethical dimensions of research and the related responsibility of the researcher. At the same time, we should urge scientists and nonscientists to explore these issues together, in an effort to restore communication and confidence.

CONCLUSION

New applications of molecular genetics are rapidly changing the relations between science, government and industry in a research field leading the search for new knowledge about fundamental life processes. Recombinant DNA is only one of several new techniques developed during the past decade which have enormously enhanced the scope and power of molecular genetics. Industrial and medical applications in this field are developing at a remarkably fast pace and will have increasingly important effects on the scientific community, the universities, and the public. The current problems generated by the stunning success of this basic research field must be addressed. Issues involving safety, ethical choices, and social and economic impact are intertwined with problems relating to patterns of government support for basic research, the role of the universities, and the social organization and value system of the scientific community. A main thrust of policy in this field should be to help define the roles and responsibilities of scientists and the public in efforts to anticipate and shape change, rather than merely reacting to it.

NOTES AND REFERENCES

1. Quoted in Terry Davidson, "DNA Meets the Public," *Somerville Journal* (15 January 1981), p. 1.

2. "Harvard Rejects Role in DNA Company," *The Harvard Crimson* (18 November 1980), p. 1. The company subsequently was established as the Genetics Institute and sought to set up operations in Somerville, Massachusetts. After the city's public hearing on the issue in January 1981, the firm withdrew its application and subsequently attempted to establish a laboratory in Boston, provoking public hearings there as well. The major scientific figure in Genetics Institute is currently head of Harvard's department of biochemistry and molecular biology.

3. Parts of the historical summary in this section parallel the account presented in Charles Weiner, "Historical Perspectives on the Recombinant DNA Controversy," in *Recombinant DNA and Genetic Experimentation*, edited by Joan Morgan and W.J. Whelan (New York: Pergamon Press, 1979), pp. 281–87. Archival source materials on the controversy over risks are available for study in the Recombinant DNA History Collection at the Institute Archives, Massachusetts Institute of Technology. For a description of the collection see Charles Weiner, "The Recombinant DNA Controversy: Archival and Oral History Resources," *Science, Technology and Human Values* (January 1979), pp. 17–19.

4. John Abelson, "A Revolution in Biology," *Science*, vol. 209 (19 September 1980), pp. 1319–21. This article introduces an entire issue of *Science* magazine devoted to technical reports on the impact of recombinant DNA techniques on fundamental knowledge of the structure, function, expression, and regulation of genes.

5. Useful sources for growth of the field are the "NIH Registered Recombinant DNA Projects" monthly computer printouts compiled by NIH. Because of recent revisions in the NIH guidelines, much of the recombinant DNA research supported by NIH is no longer registered and is not included in current reports.

6. Estimate provided by the Environmental Protection Agency.

7. The *Federal Register*, and the *Recombinant DNA Technical Bulletin* published by NIH, provide documentation of the changes in the guidelines, as do the minutes of the NIH Recombinant DNA Advisory Committee.

8. The meeting of IBC chairpersons was held on 24–25 Nov. 1980 in Washington, D.C. An account is given in the *Pharmaceutical Manufacturers Association Newsletter* (1 December 1980), p. 5, and a full report has been prepared by NIH for the Recombinant DNA Advisory Committee.

9. U.S. Senate, Committee on Commerce, Science, and Transportation, *Industrial Applications of Recombinant DNA Techniques*, hearings before the Subcommittee on Science, Technology, and Space, 20 May 1980.

10. Risk assessments that were particularly influential include the Falmouth Workshop in June 1977 (proceedings published as a special volume of *Journal of Infectious Disease*, vol. 13 [May 1978], Sherwood Gorbach, editor); the Ascot Workshop in January 1978 (*Federal Register* [28 July 1978], part 4, app. E); and the Rowe-Martin experiment (Mark A. Israel, Hardy W. Chan, Wallace P. Rowe, and Malcolm A. Martin, "Molecular Cloning of Polyoma Virus DNA in *Escherichia Coli:* Plasmid Vector System," *Science*, vol 203 [2 March 1979], pp. 883–87; and Hardy W. Chan, Mark A. Israel, Claude F. Garon, Wallace P. Rowe, and Malcolm A. Martin, "Molecular Cloning of Polyoma Virus DNA," *Science*, vol. 203 [2 March 1979], pp. 887–92).

11. Barbara Rosenberg and Lee Simon, "Recombinant DNA: Have Recent Experiments Assessed All the Risks," *Nature*, vol. 282 (20–27 December 1979), pp. 773–74; Stuart Newman, "Tumor Virus DNA Hazards No Longer Speculative," *Nature*, vol. 281 (20 September 1979), p. 176. Discussions of risk assessment by the RAC are summarized in the minutes of its meetings.

12. NIH, "Program to Assess Risks of Recombinant DNA Research: Proposed First Annual Update," *Federal Register* (17 September 1980), part 2.

13. Statements at hearing of the Cambridge Biohazard Committee, 28 Oct. 1980.

14. Proceedings of these hearings are available in National Institutes of Health, Recombinant DNA Research: *Documents Relating to "NIH Guidelines for Research Involving Recombinant DNA Molecules,"* vol. 1 (August 1976), vol. 2 (March 1978).

15. The guidelines now state that at least 20 percent of the members of the RAC shall be knowledgeable in applicable law, standards of professional conduct and practice, public attitudes, the environment, public health, occupational health, or related fields.

16. Attendance at RAC meetings is recorded in the minutes of the committee.

17. Among the few detailed evaluations are Rae Goodell, "Public Involvement in the DNA Controversy: The Case of Cambridge, Massachusetts," *Science, Technology and Human Values* (Spring 1979), pp. 36–43; and Sheldon Krimsky, "A Citizen Court in the Recombinant DNA Debate," *Bulletin of the Atomic Scientists* (October 1978), pp. 37–43.

18. Rae Goodell, "The Gene Craze," *Columbia Journalism Review* (November-December 1980), pp. 41–45; Spyros Andreopoulos, "Gene Cloning by Press Conference," *New England Journal of Medicine* (27 March 1980), pp. 743–46.

19. Stephen P. Strickland, *Politics, Science and Dread Disease: A Short History of U.S. Medical Research Policy* (Cambridge: Harvard University Press, 1972). See also Strickland, *Research and the Health of Americans* (Lexington, Mass.: D.C. Heath and Co., 1978).

20. Andreopoulos, "Gene Cloning by Press Conference," *New England Journal of Medicine*.

21. Supreme Court of the United States, *Diamond, Commissioner of Patents and Trademarks v. Chakrabarty*. No. 79–136. Argued 17 March 1980, decided 16 June 1980.

22. Among the responses were several articles in the *Hastings Center Report*, Oct. 1980: Lee Ehrman and Joe Grossfield, "What Is Natural, What Is Not?" pp. 10–11; Key Dismukes, "Life Is Patently not Human-Made," pp. 11–12; and Harold P. Green, "Chakrabarty: Tempest in a Test Tube," pp. 12–13. See also Harold J. Morowitz, "Reducing Life to Physics," *New York Times* (23 June 1980), op-ed page.

23. Philip Siekevitz, "Of Patents and Prizes," *Trends in Biochemical Sciences*, vol. 5 (September 1980), pp. vi, viii.

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25. Letter to the editor from Richard C. Lewontin, *Harvard Crimson* (16 November 1980); "Profit—and Losses—at Harvard," editorial, *New York Times* (13 November 1980), p. A34.

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27. Ibid.

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29. Letter from Joshua Lederberg to Senator Gaylord Nelson, 15 June 1978, quoted in Andreopoulos, "Gene Cloning by Press Conference," *New England Journal of Medicine*.

30. U.S. House of Representatives, Committee on Science and Astronautics, *Technology: Processes of Assessment and Choice, Report of the National Academy of Sciences* (Washington, D.C.: July 1969), pp. 32, 34, 35. The NAS report was discussed in the context of recombinant DNA issues in 1978 by Susan Wright (see bibliography).

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32. Minutes, Meeting No. 4, 15–16 September 1980, President's Commission for the Study of Ethical Problems in Medicine and Biomedical and Behavioral Research; Richard Roblin, "Human Genetic Therapy: Outlook and Apprehensions," in *Health Handbook*, George K. Chacko, editor (New York: Elsevier-North Holland Publishing, 1979), pp. 103-14; "Ethical Issues in the Biological Manipulation of Life," in *Faith and Science in an Unjust World: Report of the World Council of Churches' Conference on Faith, Science and the Future*, MIT, 1979, vol. 2, Paul Abrecht, editor (Geneva: World Council of Churches), pp. 49–68.

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5

Choosing Our Pleasures and Our Poisons: Risk Assessment for the 1980s

*William W. Lowrance**

INTRODUCTION

It only takes a few highly charged terms to evoke the risk-assessment milieu of the past decade: DDT, the Pill, saccharin, "Tris," asbestos, nuclear waste, Three Mile Island, smoking, black lung, Clean Air Act, Delaney clause, recombinant-DNA, 2,4,5-T, "Reserve Mining versus EPA," Teton Dam, DC-10. . .

This rash of accidents, disruptions and disputes has left the public and its leaders fearful that the world is awfully risky, and that although science can raise warnings, when crucial decisions have to be made science backs away in uncertainty. Further, there is a feeling that as with medical catalepsy, in which the simultaneous firing of too many nerves draws the body into spasms, the body politic has been drawn into a kind of regulatory catalepsy by too many health scares, too many consumer warnings, too many environmental lawsuits, too many bans, too many reversals. A related complaint is that we are afflicted with excessive government intervention, often of a naive, or trifling, or naysaying sort. Among professional analysts as well as members of the public there is a conviction that many risk-reduction efforts are disproportionate with the relative social burden of the hazards.

Public apprehensiveness has a number of causes. Is life becoming riskier? Not in any simple sense. As the next section of this report will demonstrate, many classical scourges have been conquered; infants get a healthier start in life; and on average people live longer lives than ever before. The historical record of floods, hurricanes, typhoons, tornadoes, earthquakes, and other geophysical disasters shows a relatively constant pattern of occurrence over the centuries.[1] (It is worth noticing, however, that migration is setting more potential victims in the path of hurricanes in the Gulf states and on top of seismic faults in California.) What we are menaced by now are enormous increases in the physical and temporal scale and complexity of sociotechnical hazards. Of these, the most threatening are risks having low-probability and high-consequence, such as genetic disaster, nuclear war, and global climate change. Too, alarm arises, in an almost paradoxical sense, because science has become so much better at detecting traces of chemicals and rare viruses, and at identifying birth defects, diseases, and mental stress. Often we know enough to worry, but not enough to be able to ameliorate the threat. Warnings and accusations are amplified by the public media, often with unseemly haste. Worse, scientific hunches are announced as scientific fact, only to have to be withdrawn later. With all this, it would be surprising if the public's sensibilities were not battered.

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Risk-related instabilities and confrontations afflicting industry and governance stem as much from problems of societal attitude and decision-making procedure as from deficiencies of technical analysis and performance. This essay will argue that assessment will be improved: if hazards are characterized explicitly, so they can be faced; if risk-aversion efforts are oriented to agreed-upon societal goals; if comparative approaches are taken that provide perspective, reveal the relative effectiveness of programs, and lead to generation of stable, defensible priorities; and if attempts are always made to weigh risks in appropriate context with benefits and costs. The paper will review some institutional efforts, problems of public perception, challenges to scientific integrity and authority, and a list of new and underattended hazards. It will conclude with recommendations.

THE EVOLUTION OF MORTAL AFFLICTIONS

In his 1803 *Essay on Population* Thomas Malthus observed of Jenner's new vaccine: "I have not the slightest doubt that if the introduction of cowpox should extirpate the smallpox, we shall find. . . increased mortality of some other disease." This general expectation holds true today if in addition to disease we include noninfectious threats. The communicable diseases of smallpox, diphtheria, typhus, cholera, tuberculosis, and polio have been conquered. So have scurvy, pellagra, and other nutritional deficiency diseases. Infant mortality has dropped dramatically. As the toll from these causes has lessened, mortality has shifted toward degenerative diseases—notably heart disease and cancer—which are attributable either to personal life style or to causative agents in the environment. While the causes of death have changed, the average age of onset of fatal illness has moved higher. Life span has lengthened. Put crudely, we die now of stroke and cancer in part because we live long enough to.

For the United States these mortality trends are summarized in Figure 1.[2]

Thus at present in the United States the leading cause of death is heart disease, followed by cancer. The rest of mortality is accounted for by other diseases and by accidents, homicide, and natural disasters (in that order).[3]

Within these gross statistics, however, there is great variability by age and socioeconomic status: motor vehicles and other accidents kill the most children under 14; for black males between the ages of 15 and 24 homicide is the largest threat; cirrhosis of the liver is the fourth leading cause of death for people between 25 and 64.

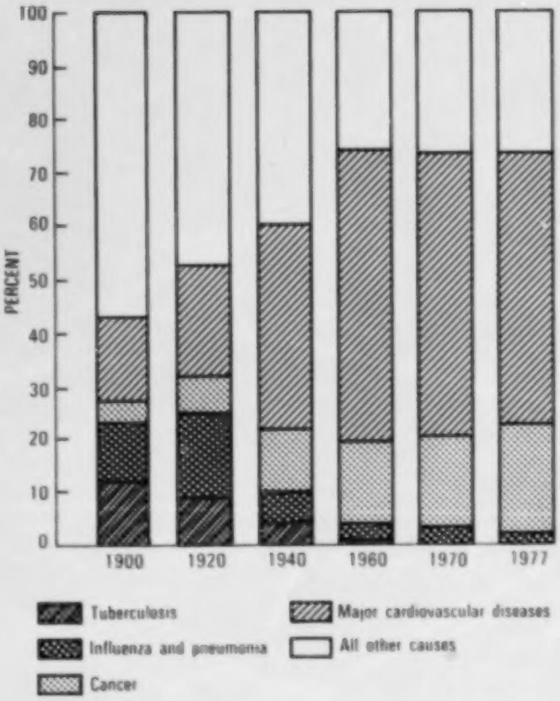

Figure 1. Deaths from Selected Causes as a Percent of All Deaths, United States.

Source: U.S. Surgeon General, *Healthy People*, 1979.

In a recent analysis of the prospects for saving lives in this country, James Vaupel developed the concept of "early deaths." (The definitional problem is fully treated in his report; for short, early death can be taken to refer to death before the age of 65.) Vaupel concluded:[4]

> The statistics indicate that the aggregate social losses due to death are largely attributable to early death and that the losses due to early death are immense, that the early dead suffer an egregious inequality in life-chances compared with those who die in old age, and that non-whites, the poor, and males suffer disproportionately from early death. Furthermore, statistics on the leading causes of death and statistics comparing non-whites and whites, males and females, current mortality with mortality earlier in this country, and the United States with Sweden and other countries suggest that early deaths could be significantly decreased.

Extrapolation of life expectancy data has led to another provocative observation about survival. Some analysts now speculate that the human species is approaching a "natural" life span limit of about 85 years. In Figure 2, the survival curve can be seen to be becoming increasingly "rectangular" and approaching a limit of 85 years. Such curves have led James Fries to predict that "the number of very old persons will not increase, that

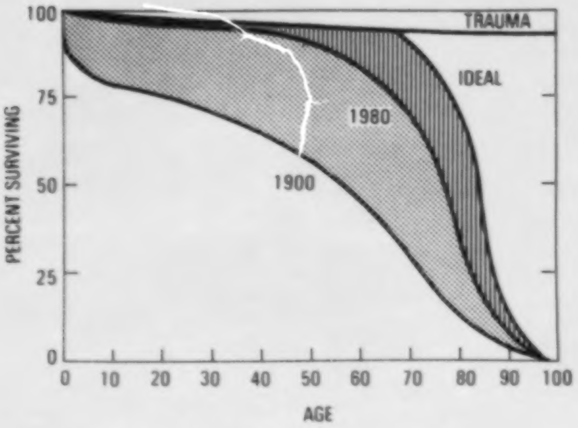

Figure 2. The Increasingly Rectangular Survival Curve.

Source: James Fries, *New England Journal of Medicine*, vol. 303 (1980), pp. 130-35.

the average period of diminished physical vigor will decrease, that chronic disease will occupy a smaller proportion of the typical life span, and that the need for medical care in later life will decrease."[5] Even if the limit is inching upward, it is doing so at a low and decreasing rate, so the implications Fries draws should remain valid within the policy-relevant time frame.

Surely, coming to terms with these trends will lead us as a society to strive less to fend off full lifetime mortality and to attend more to illness, accidents, and to quality of life. Among occupational diseases demanding attention, for instance, are the pneumoconioses: black lung disease, asbestosis, and brown lung (textile dust) disease; among the most debilitating, lingering, and painful conditions, arthritis, emphysema, and allergies; among "life style" diseases, cirrhosis of the liver and the venereal diseases.

IMPROVEMENTS IN ASSESSMENT

BECOMING MORE COMPARATIVE

As a society we find ourselves, relative to all previous human confrontation with mortal risk, in the enviable but emotionally unsettling situation of living longer and healthier lives than ever before; of not having to remain ignorant and vaguely apprehensive of hazards, but of understanding many of their causes, likelihoods, and effects; and of having now accumulated substantial experience in predicting, assessing, reducing, buffering, and redressing harm. Blissfulness is prevented by our having too many options. If we still lived only on the margin of survival, we would not have the luxury of worrying about microwaves and hair dryers. If we lacked scientific understanding and the prospect of taking preventative action, we would be more fatalistic about legionnaires disease and toxic shock syndrome. If we had not established the hurricane warning network and the national air traffic control system, we would not have to argue about their budgets.

As Howard Raiffa made the central analytical point recently in congressional hearings,[6]

> We must not pay attention to those voices that say one life is just as precious as 100 lives, or that no amount of money is as important as saving one life. Numbers do count. Such rhetoric leads to emotional, irrational inefficiencies and when life is at stake we should be extremely careful lest we fail to save lives that could have easily been saved with the same resources, or lest we force our disadvantaged poor to spend money that they can ill afford in order to gain a measure of safety that they don't want in comparison to their other more pressing needs.

To proceed in dealing with risks without making comparisons, both of import of threats and of marginal risk-reduction effectiveness (and cost-effectiveness) of public programs, makes little sense. Yet surprisingly little sophisticated comparative work has been done.

In studies meant to be illustrative, Bernard Cohen, Richard Wilson, and others have assembled catalogues of common risks. Cohen has calculated effects from different hazards upon life expectancy (for people at specified ages). He finds that cigarette smoking reduces U.S. male life expectancy by six years on average. Being 30 percent overweight reduces life expectancy by about four years. Motor vehicle accidents cut off 207 days. And assuming that all U.S. electricity came from nuclear power and that the unoptimistic risk estimates published by the Union of Concerned Scientists are correct, nuclear accidents would claim two days from the life of an average citizen.[7] Regrettably, the Cohen and Wilson calculations are based on very unreliable data, fail to take into account indirect effects, and are flawed in numerous ways. Their most valuable lesson has been to illustrate how difficult it is to reduce complex social phenomena, such as cigarette smoking and nuclear power generation, to single scalar risk rankings.

Stimulated in part by the early contributions of Chauncey Starr, over the last decade assessors have attempted to compare technological hazard to natural hazard.[8] For example, the so-called "Rasmussen Report" attempted to compare nuclear reactor accident risks to those of meteorite impacts and other natural hazards in order to provide some intuitive grounding.[9] The difficulty is that reliable numbers are hard to compute, and since polls have shown that most people, including scientists, do not have a very accurate intuitive sense of the likelihood and magnitude of natural hazards, such grounding may not be very useful anyway.[10]

The next logical step has been to try to compare the relative impacts various risk-reduction measures make on longevity. Shan Pou Tsai and colleagues, for example, have examined the question of what gains in life expectancy would result if certain major causes of death were partially eliminated. They calculated that for a newborn child, reduction of cardiovascular disease by 30 percent nationally would add 1.98 years to life expectancy at birth; 30 percent reduction of malignant cancers would add 0.71 years; and 30 percent reduction of motor vehicle accidents would add 0.21 years. If such 30 percent causative reduction were to exert effect during the working years 15 to 60, there would be gains of 1.43 years (cardiovascular), 0.26 years (cancer), and 0.14 years (motor vehicle accidents). "Even with a scientific breakthrough in combating these causes of death," the authors concluded, "it appears that future gains in life expectancies for the working ages will not be spectacular."[11]

Richard Schwing has published similar illustrative calculations of longevity extension. His findings for American males, shown in Figure 3, chart the longevity increases and crude mortality rate decreases that would occur if certain causes of death were eliminated. It is obvious that further campaigns against tuberculosis would help few men and add only weeks of life for American men on average, whereas reduction of heart disease would add years of life for a great many men.[12]

Schwing has gone on then, as others have, to compare the extent to which various risk-reduction measures—such as requiring that automobiles be built with energy-absorbing steering columns, penetration-resistant windshields, or dual brake systems—extend longevity, and to compare their cost-effectiveness (in dollars cost per person-year of life preserved).

Obviously the outcome of comparisons is heavily dependent on the way the boundaries of comparison are set. Nowhere has this been better illustrated than in recent attempts, such as the studies by the NAS Committee on Nuclear and Alternative Energy Systems (CONAES) and by Robert Inhaber, both of which compared competing energy cycles.[13, 14] In calculating the risks of coal, do we count deaths from train wrecks, air pollution, or release of radioactive radon from the burning fuel? In assessing nuclear power, do we include terrorist abuse, or nuclear weapons proliferation? In appraising solar sources, do we include health effects on copper and glass workers? There is no avoiding such analyses. The problem is to learn how to perform them with technical sophistication and to take due account of all relevant social considerations. Overreaching is hard to avoid. The consolation of most such ambitious studies has been that the process of assessment has itself sharpened the social debate and clarified technical-analytic needs.

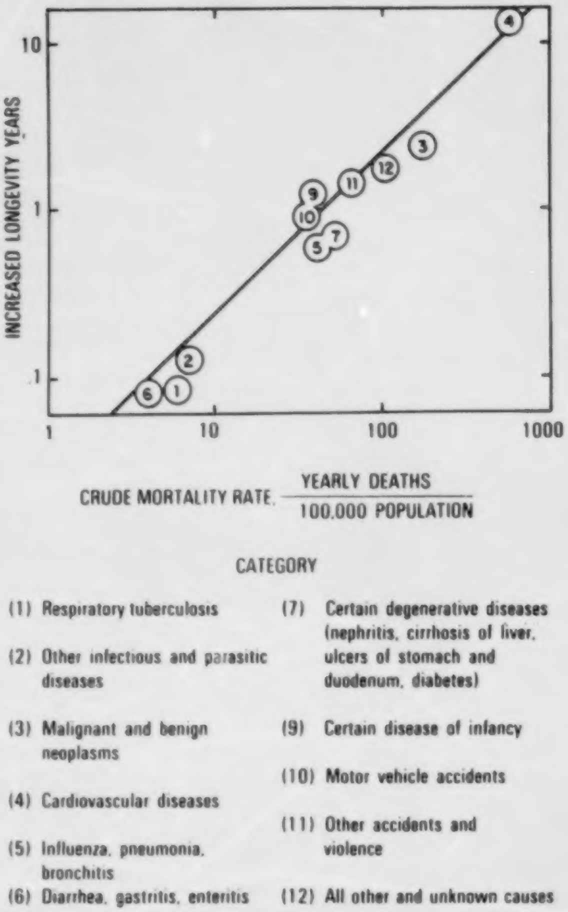

Figure 3. Increased Longevity from Elimination of Hazards, for U.S. Males.

Source: Richard Schwing, *Technological Forecasting and Social Change*, vol. 13 (1979), pp. 333–45.

That the general public is sophisticated enough to understand and endorse the idea of comparative risk assessment has been demonstrated in such situations as that in Britain at Canvey Island. Within an area of 15 square miles on that island in the Thames near London are oil refineries, petroleum tanks, ammonia and hydrogen fluoride plants, and a liquefied natural gas facility. When a few years ago controversy arose as to whether Canvey's 33,000 people were exposed to unusually high risks, a thorough government inquiry was conducted. Upon deliberation the residents passed a resolution that no further construction be accepted until the overall industrial accident risk on the island had been reduced to the average level for the United Kingdom. But they did not demand that their neighborhood be risk-free.[15]

That the same toleration for comparative approaches holds in the United States is evident in industrial areas, such as Ohio and New Jersey, where residents are demanding cleanup but not closing of industries. Similar moderation led the voters of Maine, an environmentally sensitive state that has had to deal with cold winters but also with proposals of supertanker ports, in their 1980 referendum to vote against measures that would have had the effect of being more restrictive of nuclear power.

If this country is to move toward more "rational" apportionment of risk-reduction and -management efforts, we must assure ourselves that there is reasonable parallel between the burden, in whatever terms, of particular risks and the avidity with which we defend against them, and that programs take into consideration age of onset of harm, degree of debilitation, longevity erosion, and cost-effectiveness of ameliorative programs. Before any of this can be done, hazards have to be stated explicitly and goals of hazard reduction agreed upon.

FACING HAZARDS EXPLICITLY

Comparative approaches are necessarily more quantitative, and they tend to force the revelation of specific consequences. As it dawns on social consciousness that even strict protection inevitably admits some residual harm, even if only by inducing exposure to the hazards of alternatives, little by little public officials have moved toward explicitness.

One of the most widely discussed test cases is that of DES (diethylstilbestrol, the growth hormone sometimes fed to beef cattle). The Food and Drug Administration (FDA) has formally proposed to allow beef producers to use this putatively carcinogenic but economically important agent if they remove it from feed sufficiently in advance of slaughter that residual DES in marketed beef does not exceed a specified extremely low concentration. In its proposal the FDA argued that "the acceptable risk level should (1) not significantly increase the human cancer risk and, (2) subject to that constraint, be as high as possible in order to permit the use of carcinogenic animal drugs and food additives as decreed by Congress. . . . A risk level of 1 in 1 million over a lifetime meets these criteria better than does any other that would differ significantly from it." The agency noted that further reduction "would not significantly increase human protection from cancer."[16] This and similar proposals are predicated on a conviction that the underlying carcinogen assessments are worst-possible-case overestimates of human risk. The DES standard is still under discussion. In March 1980 FDA Commissioner Goyan stated that he would favor amending the food additives laws so that the chemicals testing out under the level of one-chance-in-a-million would be permitted (the Delaney clause prohibits even minute traces of very weakly testing carcinogenic additives—a prohibition honored mostly in the breach, because of its absolutist nature).

One by one as cases have developed—the 1979 Pinto lawsuit, the national review of earthwork dams, amendment of the Clean Air Act—there has been a tendency to require that an upper bound on the estimated actual hazard be stated.

SPECIFYING RISK MANAGEMENT GOALS

Although industrial and legislative programs usually operate under guidelines mandating "reduction of harm" or "protection of consumers," the degree of reduction or protection is often not specified (except when absolute protection is called for, which, usually being impossible, simply amounts to defaulting). Goal ambiguities may remain even when program objectives are spelled out. Different goals may come into conflict: reducing use of asbestos insulation, in order to protect miners and insulation installers, may have the effect of increasing fire hazard in buildings; forbidding black airmen who are sickle-cell-trait-carriers to serve as Air Force pilots, to avoid the possibility of their becoming functionally impaired under emergency oxygen loss, conflicts with equal opportunity goals.

Recognizing that better guidance must be developed for choosing among the many available but costly marginal improvements in technical safeguards, the Advisory Committee on Reactor Safeguards of the Nuclear Regulatory Commission (NRC) has urged the NRC to consider establishing "quantitative safety goals for overall safety of nuclear power reactors." These goals might specify, for instance, physical performance criteria ("leaking of 10 percent of noble gas inventory from reactor core into primary coolant no more than once in 200 reactor years") or limits on health risk ("no more than one accident death per 1000 megawatts of electricity generated"). The Advisory Committee recently published *An Approach to Quantitative Safety Goals for Nuclear Power Plants,* and the Commission has set in motion a "plan for development and articulation of NRC safety objectives."[17] Goals in this case include far more than the goal of generating economically competitive electricity.

A recent Rand Corporation study for the Department of Energy (DOE), *Issues and Problems in Inferring a Level of Acceptable Risk,* lists types of risk-reduction goals that can be considered, such as minimization of maximum accident consequences; minimization of probability of most probable accident; and so on. After describing ways in which goal choices can make a difference to programs, the report urges that "DOE and other agencies need to be self-aware in specifying risk-reduction goals, as well as in relating them to goals of other agencies and interested parties, and understanding their implications for the choice of energy alternatives."[18]

Skeptics may be tempted to dismiss this topic, saying that we in this country do not have a consensus on social goals. Rebuttal to that too-simple dismissal is evidenced, for example, in the way our medical X-ray protection practices, which are the result of decades of reassessment and improvement by industry, medicine, and government, pursue goals: minimization of probability of damage (by decrease in frequency of use of diagnostic X-rays, compensated for by more sensitive films); minimization of potentially irreversible damage to the human gene pool (special protection of gonads); and minimization of threat to infants *in utero* (again, special protection). The typically American goal of helping disadvantaged citizens underlies special health programs for minority groups. The goal of preserving maximum consumer choice can be seen as a goal of food quality programs.

Setting goals is not impossible, but setting realistically attainable goals is not easy. It is imperative that programs be tailored to goals more precise than "protection of all Americans against all harm."

WEIGHING RISKS IN CONTEXT WITH BENEFITS AND COSTS

All decisions, indirectly or directly, rely on judgments of the sort Benjamin Franklin referred to as "prudential algebra." Under the Toxic Substances Control Act the Environmental Protection Agency (EPA) must protect the public against "unreasonable risk of injury"; under the stationary-sources provisions of the Clean Air Act it must ensure "an ample margin of safety"; under the Safe Drinking Water Act it must protect the public "to the extent feasible. . . (taking costs into consideration)." "Unreasonable," "ample," and "feasible" are not defined in these laws. For the EPA the question is not whether analysis but what form of analysis, taking what considerations into account. For all such risk reduction regimes the day has passed that benefits and costs could be ignored.

Every segment of industry and government—food, energy, transportation—has to ask of its decision-making:

- Are there ways to bring benefits and costs into consideration along with risks? Do existing policy and managerial rules allow consideration of all such factors? Should they?
- Which methodological approaches (cost-benefit analysis, decision theory, cost-effectiveness analysis, etc.) are appropriate?
- How should secondary, indirect, and intangible effects be brought into consideration?
- Are formal, explicit, published analyses required to form the basis of decision, or are they used as informational background only?
- What are the procedural rules by which definitions, analytic boundaries, and conceptual assumptions are established?
- Should those reviewing a technological option be required to review the attributes of alternatives also?

After a decade of concentrating on the negative side of the ledger, society is now trying to learn how to measure benefits. The National Academy of Sciences' 1977 study of ionizing radiation ("BEIR II") struggled with the issue of how to appraise the benefits of such applications as medical X-rays.[19] The Academy's 1979 *Food Safety Policy* report analyzed the benefits of saccharin and of food-safety policies regarding mercury, nitrites, and aflatoxin (in peanut butter),[20] and its 1980 report, *Regulating Pesticides*, described the methods available for estimating marginal gains in crop yield and benefit expected from a candidate pesticide.[21]

Several methods, usually for shorthand referred to as "risk-benefit" or "cost-benefit analysis," are available for constructing a balance sheet of desirable attributes against undesirable ones. Analysis is thus a problem of handicapping what will happen (the odds of a destructive flood, the probable incidence of a disease) and comparing quantities that are rarely expressible in common-denominator terms (social cost of lives shortened, benefits of production, risks of genetic mutation).

With some (few) well defined projects for which goals and constraints are agreed upon by the major affected parties, for which health and environmental risks, costs, and benefits are well known and understood, not only in magnitude but in social distribution, over both the near and long term, risk-benefit accounting has proven itself useful. Under such (rare) circumstances of certainty, commonsensical estimates as well as more formal analyses derived from operations research are applicable. The latter tend to be favored by specialists, technical or otherwise, who have been given a specific task to accomplish (the Army Corps of Engineers has pioneered in their use). The occasional "successful" application of such techniques—and, one suspects, also the all-embracing ring of their title—tempts legislators, administrators, managers, and judges to call for their use.

The griefs of analysis could fill a large set of books. Most reviews conclude that such approaches are very useful for structuring discussion, but are less useful or even subject to misuse when granted formal, legalistic weight. In their *Primer for Policy Analysis* Edith Stokey and Richard Zeckhauser warned:[22]

> Benefit-cost analysis is especially vulnerable to misapplication through carelessness, naivete, or outright deception. The techniques are potentially dangerous to the extent that they convey an aura of precision and objectivity. Logically they can be no more precise than the assumptions and valuations that they employ; frequently, through the compounding of errors, they may be less so. Deception is quite a different matter, involving submerged assumptions, unfairly chosen valuations, and purposeful misestimates. Bureaucratic agencies, for example, have powerful incentives to underestimate the costs of proposed projects. Any procedure for

> making policy choices, from divine guidance to computer algorithms, can be manipulated unfairly.

These and other critics respond to their own complaint by acknowledging that "prudential algebra" of one form or another must be resorted to nevertheless.

All analytical approaches have difficulty with scientific uncertainties; with fair and full description of societal problems; with predicting all possible consequences; with placing a "price" on human life and environmental goods; with taking into account intangibles and amenities in general; and with assessing the social costs of opportunities precluded.[23] A lively theater for this ongoing debate has been the proceedings of the Occupational Safety and Health Administration (OSHA) on regulation of occupational carcinogens.[24]

A somewhat different approach, "cost-effectiveness analysis," considers a present situation and compares how effectively alternatives can achieve stated objectives: automobile seatbelts compared to other forms of passive restraint, or kidney transplants compared to dialysis. Under the stimulus of cost-control campaigns analysts have developed ways of comparing the relative cost-effectiveness of competing medical screening techniques and of other medical technologies.[25] Recently the congressional Office of Technology Assessment published a useful report on *The Implications of Cost-Effectiveness Analysis on Medical Technology*.[26]

Concluding a review for the Administrative Conference, Michael Baram argued:[27]

> In practice, regulatory uses of cost-benefit analyses stifle and obstruct the achievement of legislated health, safety, and environmental goals. . . Further, to the extent that economic factors are permissible considerations under enabling statutes, agencies conduct cost-effectiveness analysis, which aids in determining the least costly means to designated goals, rather than cost-benefit analysis, which improperly determines regulatory ends as well as means.

Currently the National Academy of Sciences is preparing a report, *Costs of Environment-Related Health Effects: A Plan for Continuing Study*, which should describe ways of building a base for accounting, in effect, for the health-cost-effectiveness of environmental controls.

There are other risk decision models. Jeffrey Krischer has recently prepared a useful annotated bibliography of applications of decision analysis to health care.[28] One of the more fully developed unorthodox approaches is the libertarian synthesis of ethics and efficacy proposed by Ronald Howard.[29]

A concluding note should be that formal analysis is still helpless to accommodate many major effects: the weapons-proliferation and terrorist risks of the spread of civilian nuclear power; the highly touted and ambi-potent benefits and risks of recombinant-DNA development; the opportunity costs from undue conservativeness in regulation of contraceptive and pharmaceutical development.

DEFINING "NEGLIGIBLE" AND "INTOLERABLE," AND SETTING PRIORITIES

A disturbing feature of the 1960s and 1970s was that as each sector of manufacturing, or municipal governance, or research, or purchasing, found itself having to confront risk problems, each had to develop its own approach and work through hearings, and scientific studies, and economic reviews, and lawsuits, and insurance disputes. The social learning process was, unavoidably, painful. So were the disruption and unpredictability caused by the lack of defensible priorities. Industries and agencies found themselves so distracted by disputes over sensational cases that they could hardly pursue their main tasks, even if their charter was to reduce major risks: neither "major" nor "minor" had been defined. Expressed in a metaphor of the time, smoldering barnfires had to be neglected while brushfires were fought.

Chastening has been accomplished. Now the challenge is to develop ways of keeping priorities clear: to avoid frittering away worry-capital on very small hazards, to prohibit unbearably large hazards, and to concentrate decision-making attention on problems that affect large numbers of people in important ways. This admonition may appear an obvious one, but our failure to protect appropriate priorities is just what has set us up for the regulatory "overload" and disproportionateness we now labor under.

This concern was expressed in the 1980 National Academy of Sciences report, *Regulating Pesticides*:[30]

> A serious flaw in the current procedure is that those compounds that receive the most publicity or pressure-group attention may not necessarily be those that present the greatest public health or environmental hazards. The current procedure does not provide for a broad comparison of the hazards posed by the large number of registered pesticides. At the same time, outside pressures to regulate a specific compound rarely arise from careful evaluation of comparative risks of alternative pesticides. To the extent that external pressures are influential in determining the order in which the [Office of Pesticides Programs] evaluates compounds, the consequence may well be that considerable resources are devoted to regulation of minor, low-risk compounds while important high-risk ones remain unreviewed for periods longer than would otherwise be the case.

The March 1979 report by the National Academy of Sciences on *Food Safety Policy* proposed that the FDA categorize foods as being of high, moderate, or low risk, and "apply severe and general constraints only to items involving the greatest, most frequent, and most certain dangers."[31]

Naturally, regulatory agencies do try to apply their most vigorous attention to the most important issues, but their problem is to set protectable priorities (ones that are buffered from sporadic undermining) so that all parties involved know the analytic and legal agenda and can allocate resources accordingly. OSHA has tried to do this with occupational carcinogens, as has EPA with chemicals regulated under the Toxic Substances Control Act. The new National Toxicological Program is taking over some of the priority-setting tasks and will try to rationalize them across agency lines. The Consumer Product Safety Commission bases its priorities in part on a "frequency-severity index" derived from a computerized hospital-emergency-room-admissions sampling system.

"Intolerable" and "unacceptable" are being invested with real-world connotations, as are "negligible" and "insignificant." These boundary-setting adjectives gain meaning in two ways: as experts, insurers, and others rank hazards in hierarchies by severity, incidence, and overall social exposure (hazards at the top and bottom of lists thus becoming obvious candidates for prohibition or acceptance), and as public opinion, lawsuits, and so on indicate endorsement of the ranking. This helps administrators and managers allocate attention to the difficult cases in the middle.

In the beef DES example described earlier, some parties are urging that real but very small low-dose risks to humans be considered "negligible." The same principle is being appealed to in a current legal dispute over the regulation of the common hair dye ingredient 4-MMPD. Seven hair coloring manufacturers have sued the FDA against requiring that products containing 4-MMPD bear a label warning that the compound "has been determined to cause cancer in laboratory animals" and "can penetrate the skin." The plaintiffs argue that this stigmatizes the products, that scientific proof of 4-MMPD's carcinogenicity is weak, and that even if the chemical is carcinogenic to animals "the risk is truly minuscule when compared to other potential or proven carcinogens. . . estimated to expose the individual consumer to a far greater risk of cancer than hair dyes containing 4-MMPD." A federal district court has remanded the case to the FDA, instructing the regulators to determine whether the chemical presents "a generally recognized level of insignificant risk to human health."[32]

In a striking case recently the FDA approved the hair dye chemical lead acetate. While acknowledging that in high doses the material is carcinogenic to rodents, the agency concluded that human exposure is so small, especially relative to overall lead intake, as not to warrant prohibition.[33]

Risk ceilings also can be established. In this and many other countries polychlorinated biphenyls (PCBs) have been banned from commerce because their carcinogenic potency is judged to be absolutely intolerable. From time to time high-technology projects have been vetoed because their risks were unthinkably high: some macroengineering modifications of the environment, and certain potentially disastrous recombinant-DNA experiments, are landmark examples. The issue may not only be whether the hazards are actuarially high, but whether the threat would have an intolerably disruptive effect, physically or psychologically, on the fabric of society.

A useful way of envisioning risks is to profile them as a curve of frequency versus severity, as has been done for illustration in Figure 4. When a number of risks are plotted this way, certain domains can be recognized as de facto rejected (that is, society has repeatedly abjured from risks in that range) or, on various grounds, as having been defined to be unacceptable. (The particular curves drawn in Figure 4 are typical of those under discussion currently; their numerical values are debatable. The basic method, though, of portraying cumulative, integrated risks in this fashion deserves exploration.)

SEEKING ACCOMMODATION BETWEEN TECHNICAL AND LAY PERCEPTIONS

It is evident that "the public" often views risk differently from the way technical analysts do. (Of course, consensus is also rare even within relatively close circles of experts.)

From what do these differences of opinion stem? First, science itself is, in effect, simply a matter of "voting"; the scientifically True is no more than what scientists endorse to be true. Empirical knowledge is developed systematically within the scientific community, subject to criteria of repeatability, controlled observation, statistical significance, openness, and the other guides of Western science. By itself procedure guarantees nothing, though. Good science is science that "works": science that can predict with consistency and generality and accuracy what will happen in the physical and social world. The weighing of facts remains subjective; perfect objectivity is a myth.

And second, judgments of hazards involve consideration not only of "size" of risks—likelihood and magnitude—but also of social value.[34] This of course leaves much room for disagreement.

Researchers have speculated that people's opinions about risks depend on many biasing factors, such as voluntariness of exposure, frequency of occurrence, amenability to personal control, reversibility, immediacy, bizarreness, catastrophic nature, and so on.[35]

Social scientists such as Paul Slovic, Baruch Fischhoff, and Sarah Lichtenstein have used polling techniques to survey risk perceptions and risk taking proclivities. What they find, to neither their surprise nor ours, is that people have different perceptual biases. This research has concluded that human beings' brains, whether expert or lay, get overloaded with risk infor-

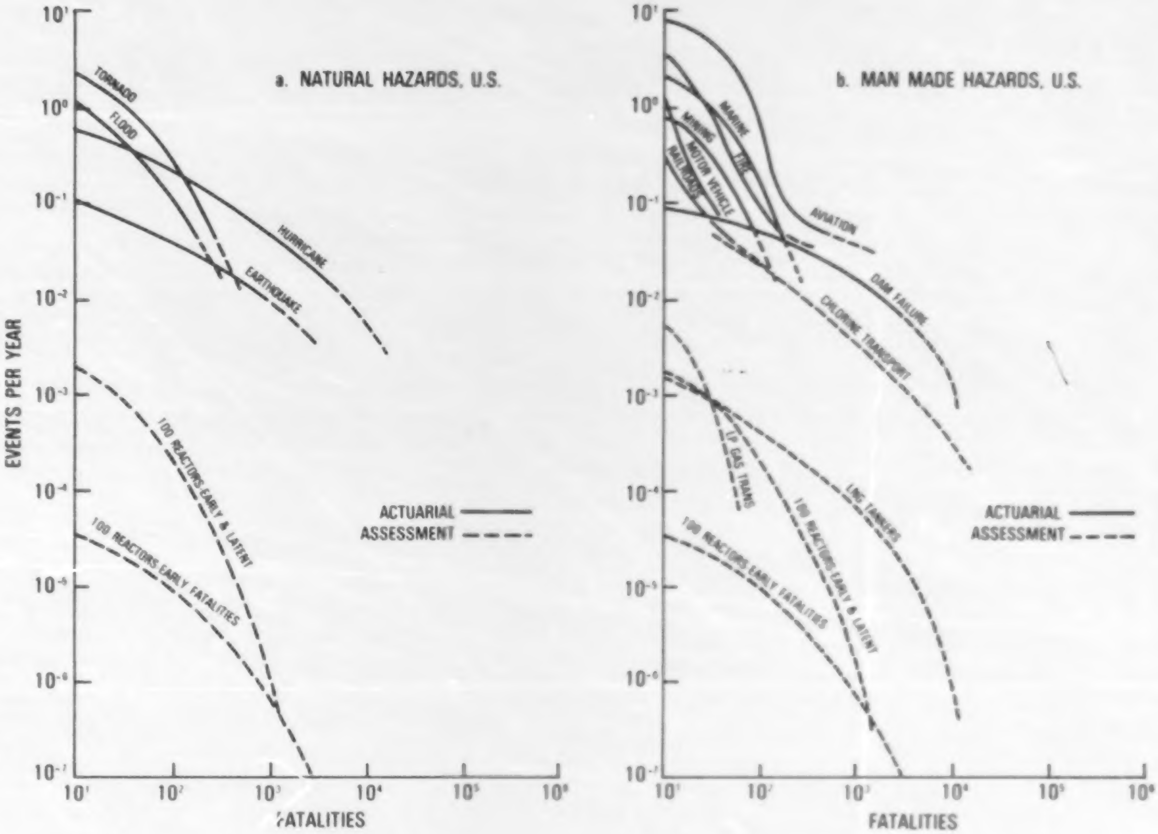

Figure 4. Frequency-Versus-Severity Profiles for Nuclear Reactor Accidents in U.S., Relative to (a) Natural Hazards, and (b) Man Made Hazards. (These curves are typical of their type, but are meant here simply to be illustrative; numbers are debatable.)

Source: Author.

mation and have trouble comparing risks; that the media accentuate social reverberations in risk disputes; and that, in essence, people believe what they want to believe. Person-in-the-street interviews of technical people show them to be not much better than nontechnical people at guessing, for example, how many fatalities are incurred annually from tornadoes, contraceptives, or lawnmowers.[36]

Many of these polling studies are open to criticism. They suffer from the usual shortcomings of questionnaire design and the generic weaknesses of polling. Often they ask about only a single hazard at a time, which by failing to foster or force comparison, and by allowing people to express self-contradictory views, provides little guidance for policymaking. They force people artificially to break down their views into components. And they are vulnerable to being assumed (not necessarily by their authors) to imply findings about "the public," when in fact most of them have only dealt with small population samples.

Daniel Kahneman and Amos Tversky have developed an approach called "prospect theory" to account for the empirical findings.[37] Now perhaps theory will guide design of more sophisticated polls.

In the risk assessment domain, as in others, we are being forced to realize that "the public" is a very elusive construct. No one person or group of people fully represents, or is representative of, all of our citizenry, and the "organized public" remains small and keeps changing in composition and opinion. For this and other reasons the notion of "public participation" lacks conceptual shape. To oppose closed bureaucratic proceedings is usually legitimate, but it is a lot harder to devise proceedings that are not only open to the affected polity but that encourage extensive "public" participation without just opening channels for special-interest lobbying. A recent Organization for Economic Cooperation and Development study of public participation, entitled *Technology on Trial*, concluded:[38]

> The general thrust of participatory demand would appear to be for a greater degree of public accountability; freer public access to technical information;

> more timely consultation on policy options; a more holistic approach to the assessment of impacts: all of which amounts, of course, to more direct public participation in the exercise of decision-making power.

In recent years both governmental and nongovernmental bodies have been taking steps to seek accommodation between lay perceptions and technical-analytic ones.[39] Regulatory agencies have opened up their proceedings and have solicited public input. Professional organizations have explored perceptual issues: in 1979 the National Council on Radiation Protection and Measurement held a symposium resulting in a volume entitled *Perceptions of Risk*.[40]

If an attitudinal bias emerges, it can be incorporated into standards. In recognition of the public's extraordinary concern about catastrophic potential (as opposed to diffuse chronic risks) of nuclear reactors, for example, industry and its regulators have incorporated "risk aversiveness," or disproportionate conservatism, into reactor safeguards.[41]

A 1980 report on *Approaches to Acceptable Risk*, commissioned by the Nuclear Regulatory Commission, provides very constructive review of many of these decisional problems.[42]

It is worth surmising that what is under perceptual dispute in many cases is not only the hazard itself but the social "management" of it. Nowhere has this been more bluntly evidenced than in the overall conclusion of the President's Commission on the Accident at Three Mile Island:[43]

> To prevent nuclear accidents as serious as Three Mile Island, fundamental changes will be necessary in the organization, procedures, and practices and—above all—in the attitudes of the Nuclear Regulatory Commission and, to the extent that the institutions we investigated are typical, of the nuclear industry.

Too, one suspects that risk opinions often may in effect be proxies for more deeply-seated opinions about corporate bigness, or bureaucratic inaction, or erosion of personal control.

INSTITUTIONAL ATTENTION

CONGRESSIONAL ACTIONS

As though swatting at swarms of hazards on all sides, during the 1970s the Congress passed, inter alia, the Consumer Product Safety Act; the Fire Prevention and Control Act; the Occupational Safety and Health Act; the Federal Water Pollution Control Act; the Toxic Substances Control Act; the Mine Safety and Health Act; the (aircraft) Noise Control Act; the Federal Environmental Pesticide Act; the National Earthquake Hazards Reduction Act; the Medical Devices amendment to the Food, Drug, and Cosmetic Act; the Safe Drinking Water Act; the Resource Conservation and Recovery Act; and various Clean Air amendments. To ensure independence of control it split the Nuclear Regulatory Commission out of the old Atomic Energy Commission. And it established the Environmental Protection Agency, the Occupational Safety and Health Administration, the Consumer Product Safety Commission, the National Fire Prevention and Control Administration, and the Federal Emergency Management Agency to administer all the new laws.

The effect of this legislative crusade has been to bring tens of thousands of hazards into regulatory frameworks of many kinds, based on science, medicine, engineering, law, and economics that were—and still are—inadequate bases for decision.

The Congress has chosen a variety of roles for itself in risk assessment. It has established the regulatory agencies and overseen their work. With some issues, such as automobile emissions, it has insisted on reviewing the scientific and economic evidence in detail and itself setting primary standards. With others, such as the arcane questions of recombinant DNA research, it has held hearings to establish a record but has refrained from instituting strong control (see the paper by Charles Weiner in this volume). Occasionally, in response to constituent pressure or political opportunity, it has intervened precipitously in regulatory action, as it has repeatedly done with saccharin, directing the FDA to stay an action or requesting the National Academy of Sciences to conduct another study. In emergencies it has held high-level inquiries, as it did during the Three Mile Island accident.

Recently the Office of Technology Assessment, the General Accounting Office, and the Congressional Research Service have all gotten more involved in preparing risk-related reports for the Congress. Congressman Don Ritter and others have proposed mandating that cost-benefit analysis be used as the basis for regulatory action; response to this bill in hearings has been mixed.[44] Congressman William Wampler has, in HR-6521, proposed creation of a National Science Council within the Executive Office (lodged in the Office of Science and Technology Policy), which would be charged with adjudicating major scientific disputes over factual matters in regulatory decision-making. Prompted by such flaps as that over the questionable studies of health risks at Love Canal, legislators are considering establishing guidelines for scientific peer review of assessments used in regulation. Congressional concern over risk issues remains high, but it tends to focus on individual hazards rather than on a comparative high-risk-reduction agenda, and it tends to favor regulation as its best instrument.

ADMINISTRATION ACTIONS

Various Executive Branch sagas in risk decision-making have been described elsewhere and will not be reviewed here. We should, however, notice several trends that go beyond the straightforward execution of regulatory mandates.

There is some movement toward interagency coordination of regulatory actions. The complexity of the administrative task is illustrated by the fact that the Interagency Review Group on Nuclear Waste Management had to be constituted from 14 major entities of government (the Departments of Commerce, Energy, Interior, State, and Transportation; NASA, ACDA, EPA, OMB, CEQ, OSTP, ODAP, NSC, and NRC).[45] The Interagency Regulatory Liaison Group (CPSC, EPA, FDA, OSHA, and USDA) has developed coordinated guidelines on carcinogenicity assessment.[46] A National Toxicology Program has been established to serve the needs of a number of agencies.

Fundamental research in support of regulatory work may be improving: the National Institutes of Health have become more involved in matters such as development of reliable and practical screening tests for carcinogens; the National Science Foundation now sponsors risk-related policy studies; and the National Bureau of Standards conducts fire research for the benefit of many agencies. How to marshall such support effectively is still a challenge: the basic research agencies don't have specific mission mandates, and the regulatory agencies lack strong fundamental research capabilities.

As part of its attempt to control economic inflation resulting from over-regulation, in March of 1978 the Carter Administration promulgated its Executive Order 12044, which directed the regulatory agencies to take a number of steps to "rationalize" their actions and to evaluate the promise of non-regulatory alternatives. Most controversially, the order called for economic impact analyses of major regulatory actions. As a result, a layer of procedures and organizations, such as the Regulatory Analysis Review Group and the Regulatory Council, was superimposed on existing, congressionally mandated agency structures. Adjustments to these developments have been painful. In his enlightening report to the Administrative Conference on these developments, Michael Baram concluded tactfully:[47]

> Obviously, regulatory reform is in a state of flux, as COWPS, CEA, OMB, OSTP, RARG, RC, the agencies and Congress act in response to the stimulus of Executive Order 12044. New controversies have arisen as to the conduct and use of regulatory analyses, the adequacy of the methodologies employed, and the timing and extent of Presidential involvement in agency decision-processes.

In its attempts to provide correctives for economically damaging over-regulation, the Reagan Administration will have to decide whether such centralized review is appropriate or whether such considerations can be delegated, with guidelines, to the agencies.

COURT ACTIONS

Thousands of tort cases are heard every year. For the present review what are important are the ongoing debates over the role of the courts, and the landmark decisions handed down by the high courts.

One respected view of the role of the judiciary is that championed by Judge David Bazelon.[48]

> Courts cannot second-guess the decisions made by those who, by virtue of their expertise or their political accountability, have been entrusted with ultimate decisions. But courts can and have played a critical role in fostering the kind of dialogue and reflection that can improve the quality of those decisions.

Others disagree, believing that courts should be free to review the substantive evidence and logic of assessments and decisions. The extent of judicial intrusion into agency decision-making will remain an issue.

Recent years have seen the courts interpreting legislative mandates (as to whether, for instance, regulation under the Clean Air Act must consider costs, or whether the FDA properly interpreted its mandate in banning laetrile), and refereeing territorial disputes between agencies.

A crucial issue that continues to work its way up to the Supreme Court relates to the imperative for cost-benefit analysis in regulatory decisions. The recent case of *Industrial Union Department, AFL-CIO versus American Petroleum Institute* side-stepped the issue of whether OSHA must, under its statutes, base its decisions—in this case, over whether to tighten occupational exposure limits for benzene from ten parts per million to one part per million—on formal, explicit, published cost-benefit analyses, the issue that many observers hoped the court would address.[49] The justices have, however, agreed to hear an analogous case, on cotton dust, in 1981. The legislative background from which the Supreme Court has to work does not provide much guidance.

NONGOVERNMENTAL ACTIONS

Several recent developments exemplify the increasingly collective initiatives being taken by nongovernmental bodies. An impressive contribution has been made by the Food Safety Council, a nonprofit coalition of industrial, consumerist, and other members, which has developed and published a thorough review of the technical problems associated with food risk assessment and made proposals that are now under consideration by regulatory and other bodies.[50] The American Industrial Health

Council, a coalition of 140 companies and 80 trade associations, has developed concerted positions on regulatory issues and is now proposing structural and procedural reforms.[51] In the aftermath of the Three Mile Island accident the country's electric utilities and nuclear industry pooled their interests and established a Nuclear Safety Analysis Center, associated with the Electric Power Research Institute, to serve as an industry-wide reactor performance clearinghouse. Some 35 major chemical firms have recently established the Chemical Industry Institute of Toxicology, a research center charged with performing state-of-the-art toxicological research and assessment of large-volume commodity chemicals (not proprietary products) for the benefit of the industry as a whole. The major U.S. automobile and truck companies have joined the EPA in establishing a Health Effects Institute to study the effects of motor vehicle pollution.[52]

It is not yet possible to evaluate the promise of these new institutions. They deserve watching because they typify efforts to develop techniques, procedures, data bases, and focal centers for risk assessment outside of government. The question will be whether the work they produce is of high technical quality; whether they develop reputations of integrity; and whether government and the courts can effectively accommodate the work of these hybrid institutions as alternatives to direct regulation and government-sponsored assessment.

It might also be mentioned that a Society for Risk Analysis has been formed, which (through Plenum Press) will in 1981 begin publication of a journal, *Risk Analysis*.

SCIENTIFIC INTEGRITY AND AUTHORITY

Serious criticism is currently being leveled at the manner and quality with which scientific analysis is brought to bear on public hazards. Not to be interpreted as disaffection with science per se, this dismay reflects confidence that science can indeed help assess these problems, if it is properly applied.

Proposals are gathering for establishment of central authority structures to which technical disputes can be appealed. For example, the New York Governor's panel (chaired by Lewis Thomas) formed to review the Love Canal fiasco found that "only further questions and debates on scientific credibility have been the result" of the "inadequate research designs" and "inadequate intergovernmental coordination and cooperation in the design and implementation of health effects studies" at the dump; as a remedy it recommended establishment of a Scientific Advisory Panel responsible to the Governor.[53] Editorials have appeared in *Science* and elsewhere calling for reincarnation of the President's Science Advisory Committee to referee such disputes. Congressional bill HR-6521 proposed formation of a National Science Council within the Executive Office for high-level review of assessments.

In somewhat the same vein the American Industrial Health Council has urged Congress to establish a Science Panel:[54]

> AIHC advocates that in the development of carcinogen and other federal chronic health control policies scientific determinations should be made separate from regulatory considerations and that such determinations, assessing the most probable human risk should be made by the best scientists available following a review of all relevant data. These determinations should be made by a Panel of eminent scientists located centrally somewhere within government or elsewhere as appropriate but separate from the regulatory agencies whose actions would be affected by the determinations.

Two questions must be asked of such proposals: whether "scientific and technical determinations" can legitimately be separated from "political and social determinations," and whether centralization of authority assures higher quality science.

To the first the answer is probably, yes, to a considerable extent, as long as it is understood that the very process of defining the problem is subjective and that scientific assessments usually have to be conducted iteratively. For example, to view the liquefied-natural-gas-facility problem as one of time-averaged risk is different from worrying about the potentially massive social disruption one large accident could cause. Complex issues, such as energy policy, have to go many rounds of assessment, criticism, redefinition, and reassessment.

To the second question the answer is that communal scientific assessments do tend to gain critical analytic strength and social legitimacy over assessments made by individuals alone, but that pluralism and variety within the scientific community should be encouraged: recruiting more skilled policy-analytic scientists and engineers in industry, government, and other organizations; appointing able advisory panels to many different administrative, legislative, and managerial bodies; upgrading assessment work in academies, professional societies, and trade organizations; and so on. Pluralism remains an essential safeguard against narrowness. Centralization and consistency are not always good in themselves. Besides, high-level bodies will always be limited to handling only a few contentious issues at a time. What they can do is raise warning flags about hazardous situations, draw attention to suspect scientific studies, and help set the national agenda of assessment.

One of the more encouraging developments of the last few years has been a willingness of technical people, acting as professional communities, to review major assessments. When the original "Rasmussen Report" on reactor safety was issued, for example, it was subjected to detailed critique by a panel of the American Physical

Society, by an ad hoc review group (the "Lewis Panel") chartered by the Nuclear Regulatory Commission, by the Union of Concerned Scientists, and by others. Currently the Society of Toxicology is critiquing the controversial "ED-01" effective-carcinogen-dose experiment performed by the National Center for Toxicological Research.

NEW AND UNDERATTENDED HAZARDS

New hazards will always be cropping up, and there is no need to develop a complete new apprehension list here. The author believes that the following can hardly escape becoming matters of heated controversy in the near future. The "thought exercise" is: how can social and technical attention most effectively be brought to focus on them?

WOMEN'S OCCUPATIONAL HEALTH

As women increasingly move into the heavy industrial workplace, there are questions of: (a) whether our scientific and medical understanding of women's bodies under stress is sufficient; (b) whether existing occupational standards protect all women as well as all men "adequately"; (c) if the answer to either (a) or (b) is "no," whether any health-related discrimination should be applied between the sexes (or, indeed, between small people and large people, or between any other categories by which human beings differ from one another) in conducting research and instituting protection; and, (d) what actions should be taken specifically.

Part of this issue has to do with reproductive health, both to pregnant workers and to the fetuses they carry. Legal suits that have centered around this issue have not yet provided much clarification. Because mutation can occur in sperms, too, men are not exempt from danger. The Interagency Regulatory Liaison Group recently announced that it is conducting a major review of reproductive toxicology.[55]

Reproductive effects are not the only ones at issue: heat susceptibility, hearing loss, skin irritation, and musculoskeletal damage may well turn out to be different for women.[56]

URBAN AND INDOOR POLLUTION HAZARDS

Sealing up indoor environments hermetically keeps cold and smog out, but it may keep indoor pollutants in. Infectious and allergenic agents can be transmitted through an office's ventilating system. The problems of flaking asbestos and old lead-based paint are still with us. In a September 1980 report entitled *Indoor Air Pollution* the General Accounting Office raised the alarm about various gases—radon, the radioactive gas released slowly from rock building materials; carbon monoxide, from various combustion sources; formaldehyde, from insulation; and others—that tend to build up and be circulated in sealed, poorly ventilated houses, mobile homes, offices, and schools.[57] There continue to be allegations that nonsmokers are exposed to significant air pollution burdens from other people's smoking.[58] Continued urbanization and the campaign to insulate and seal buildings in efforts to save energy can only exacerbate these risks.

TEENAGE PREGNANCY

It is hard not to be struck numb by this problem. As expressed by James Vaupel:[59]

> One area seems particularly important. It involves the complex of overlapping problems associated with teenage birth, illegitimacy, prematurity, low birth weight, low IQ, deficient pre-natal and infant care, and high mortality rates not only for those children in infancy but also later on in life and for the mothers. The number of teenage births is startling: nearly 600,000 infants were born in 1975 to teenage mothers, some 240,000 to mothers age 17 or younger.

Surely these numbers speak for themselves. Can any health risk be larger? To wave these problems off to "social welfare" bureaus and not address them along with the major issues on the national risk-reduction agenda is to take a very narrow view.

SEISMIC HAZARD

Earthquake experts continue to predict major shocks for the West Coast. Engineers warn that although high, modern buildings are earthquake-resistant, considerable peril remains in older, lower buildings. Fire hazard accompanies earthquake hazard in inhabited areas. As an exercise, officials might ask themselves how they will defend their current actions after the Big One strikes. Many of the problems are technical-economic ones that lend themselves to comparative analysis, as a recent Executive Branch review of California seismic hazard preparedness has argued.[60]

RECOMMENDATIONS

(1) The overall urging of this essay is that bodies responsible for appraising public risk ask of their assessment efforts:

- Are risks, benefits, and costs characterized as explicitly as possible?
- Are uncertainties and intangibles acknowledged and where possible, estimated?
- Are programs oriented to agreed-upon societal goals?

- Do procedures guarantee that high-quality technical evidence is made available and used as the basis for decision?
- Are risks examined in a properly comparative context along with benefits and costs?
- Are precautions taken to prevent minor hazards from displacing larger ones on the protection agenda?
- Are the formality and legal bindingness of the analytic base appropriate?

(2) Excerpts of well-regarded risk assessment studies should be collected and published with commentary. (The National Academy of Sciences' Food Safety Study published several examples, and the Academy's current review of some of its past projects—the "Kates study"—will provide more.) Critique should be made not only of analytic methodology but also of how boundaries of assessment were set, how assessors were chosen, how conflicts-of-interest and biases were dealt with, how findings were expressed, and how the study groups maintained their relationships with patrons and clients.

(3) The causal connection between environment and health deserves continued investigation. As part of this, baseline surveys like the "LaLonde Report" (*Health of Canadians*) or the 1980 *California Health Plan* should be developed for the United States; this would be an extension of the 1979 *Report of the U.S. Surgeon General on Health Promotion and Disease Prevention*. Then those determinants of health that are amenable to environmental influence should be evaluated.

(4) The Office of Management and Budget, the Congressional Budget Office, or others might direct or commission comparative evaluations of the marginal longevity gains and other benefits from key regulatory programs.

(5) Evaluation should be made of such longstanding risk-management regimes as food inspection programs, fire-prevention provisions of building codes, flood plains insurance, black lung insurance, and the like, asking whether they accomplish their risk-spreading or risk-reduction goals.

(6) As the nation contemplates deregulation, sectoral net-assessment of regulatory policies should be conducted and critiqued. Alternatives to regulation should be examined, especially hybrid nongovernmental/governmental approaches.[61] In this regard the experiences of other countries, such as Sweden's in food safety, should be reviewed.

(7) High-level scientific leadership needs continual renewal. One function of an upgraded White House scientific advisory body should be to identify major risk issues needing attention (such as, for example, the under-attended issues cited at the end of this paper). This or other groups should consider setting up a watchdog commission like the United Kingdom's Advisory Committee on Major Hazards to lead in the anticipation and assessment of important, long-term hazards.

(8) There are many specific research needs, ranging from toxicology to policy analysis. Broad topics deserving attention include:

- Evaluation of the overall predictive usefulness of the toxicological gauntlet through which chemical products now are required to be run.[62]
- Improvement of epidemiology as an analytical complement to toxicological testing, and continued development of the necessary databases.
- Refinement and comparison of such analytical techniques as cost-benefit analysis, decision theory, cost-effectiveness analysis.
- Evaluation of the validity of fault-tree and event-tree analysis as applied to nuclear reactors and other engineered structures.[63]
- Investigation of ways in which human error (maintenance error, operation error, emergency-response error) can be taken into account in probabilistic assessment of technological systems.

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II SCIENCE, TECHNOLOGY AND INTERNATIONAL SECURITY

6 Science, Technology and International Security: A Synthesis

*Eugene B. Skolnikoff**

INTRODUCTION

In a world substantially altered in this century as a result of the products of research and development, and with the elements of security of most nations directly affected, government institutions and policy processes in the United States remain heavily domestic in orientation. Contrary to common assumption, this is at least as true for the scientific and technological enterprise as it is for any other.

Some of the most important issues and needs relevant to science, technology and international security, are presented in the following pages and in the accompanying papers. The parochial nature of U.S. national institutions, however, makes it peculiarly difficult to come to grips with some of these needs, or to anticipate them in any orderly way. For many years this problem has plagued U.S. government attempts to deal with the international implications of research and development (R&D), and international science and technology. The problems and the dangers now become more pressing as scientific and technological competence in other nations becomes more formidable. New measures are needed, yet the issue of excessive domestic orientation is only rarely identified or directly confronted. Without some attempt to understand this issue, actions that focus on the specific needs discussed below are likely always to remain ad hoc, and seldom equal to their tasks.

BACKGROUND

The results of science and technology have had dramatic effects on the restructuring of nations and of international affairs, particularly in the 35 years since the Second World War. Aircraft, satellite communications, health and sanitation measures, missiles, nuclear weapons, automated production, radio and television, agricultural mechanization, and new crops strains all bear witness to the productivity of R&D and, in their effects, to the profound revolution in human affairs they have brought about or made possible. The pace of change, furthermore, shows no sign of slackening.

International affairs have been heavily influenced by the differential ability of nations to carry out and capitalize on the results of R&D. Two nations have emerged with military power and influence far greater than others largely as a result of natural endowments and resource bases that have allowed massive exploitation of science and technology. The gradual decay of that dominance, especially in its economic dimension, is already a source of new international relationships and problems. The disparity among nations of the North and South in ability to acquire and exploit technology is also a major factor in their relative economic status, and in their increasingly acerbic political relations.

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Concurrently, the pace of industrialization of technological societies has greatly intensified the dependency relations among states, so that even the most advanced societies find themselves critically dependent on others for resources, information, capital, markets, food, and even technology.

Traditional geopolitical factors have been altered or expanded by advances in science and technology to include, inter alia, size and number of long-range nuclear missiles, satellite communications and surveillance capability, competence of the educational system, fundamental change in the very significance of major conflict, and critically, R&D capacity.

The results of R&D have also given rise to new technologies of global scale, creating wholly new issues in international affairs, notably atomic energy and space exploration. Also a matter of worldwide concern are the side effects of technological development. The resultant changes have altered traditional international issues and created major new ones, such as transborder environmental concerns, stratospheric modification, and ocean exploitation.

Not all of these changes in international affairs directly bear on security, but the web of interactions in a technological world makes it difficult, even misleading, to exclude, say, economic concerns of developing countries from the concept of international security. In fact, the broad issues of food, health, resources, energy, and population are aspects as legitimately a part of security as are military issues.

Given these effects of science and technology on the international security of states, it is ironic that the support for science and technology is primarily a national endeavor, particularly in the United States. Policies for R&D are seen in a national perspective, and come primarily from national governments. This means, however, that international or global needs are not likely to be adequately taken into consideration in a national decision process.

A natural result of the nation/state system is that decisions in all policy areas are usually made unilaterally within one nation. Moreover, the apparent worldwide intensification of nationalism in the face of economic difficulty, not least in the United States, further encourages unilateral decision-making. The parochial nature of decisions concerning R&D, however, goes beyond normal constraints of nation-based decision-making and funding. The decentralized nature of public funding for research means that it is predominantly considered within the context of mission agency budgets. Even for those agencies whose rationale has a basic foreign policy motivation (DOD, DOE), the actual decisions and choices are heavily influenced by domestic pressures and inputs. Some departments or agencies are in fact precluded by their legislative charters from committing resources for anything other than domestic problems. All are faced with a budget process, in both the Executive and Legislative branches, that discourages (or often denies) all departments except foreign policy agencies the right to allocate their own R&D funds for other than U.S.-defined problems.

In the private sector as well, research decisions are heavily conditioned by the U.S. market, with American industry still primarily concerned with U.S. sales, and only gradually adjusting to the growing share of exports in the economy.

The implications of this situation are evident throughout the discussion of specific issues below, and deserve subsequent elaboration to suggest possible policy or institutional departures that could be undertaken.

Of course, not all issues are handicapped by this particular institutional limitation. What follows is a broader discussion of the issues in the interaction of science, technology and international security that are likely to be central questions over the next five years. Though the focus is on a five-year period, policies cannot sensibly be seen in that short time frame without taking into account long-term objectives. Where relevant, what are in effect assumptions about desirable futures will be spelled out. The final section will be concerned with some of the institutional and policy process questions raised by the specific issues.

KEY ISSUE AREAS

It is tempting to start with national security issues, which appear to be most directly related to the subject. But, economic issues will probably receive policy priority in the next few years, with important consequences for international security. In addition, as significant as defense issues are, they tend to receive more concentrated attention. Hence, defense issues will be addressed later in this paper, without in any way denying the fundamental significance of science and technology to security issues and, particularly, to international stability.

ECONOMIC ISSUES

Competition and Cooperation Among Advanced Industrial Countries

It is not a novel observation that the most serious short-term problem of the United States and of other Western industrialized nations is and will continue to be coping with inflation in a largely stagnating economic situation.

Unemployment rates are high in many countries (over 9 percent in the United Kingdom at the end of 1980), with inflation at the double-digit level for several. The relatively bleak economic outlook has many causes; analysis of them within the context of this paper would be inappropriate. However, not only do economic problems affect the international role of science and technology, but some measures individual countries may take for economic purposes will affect the course of science and technology or limit the international flow of scientific and technological information.

Industrial Policy It has become almost a fad to speak of the need in the United States for an industrial policy or for reindustrialization. Several aspects of reindustrialization are particularly relevant to R&D. One is the ability (legal, political, and psychological) of the United States government to work cooperatively with individual companies or a consortium to support research designed to improve the international competitive position of U.S. industry. Antitrust considerations, among others, have deterred such joint activity in the past.

Two initiatives in the Carter administration have shown that at least some of the barriers can be overcome. The joint research programs on automobile engines, with a consortium of auto companies (Cooperative Automotive Research Program), and the cooperative program for ocean margin drilling, with a group of oil companies, have received the advance blessing of the Department of Justice. These initiatives are now in jeopardy or cancelled. The international economic payoffs of cooperation of this kind (and the costs of not easing the way) may justify reconsideration of this policy in the next several years. Whether or not the government is involved, the advantage to international competitiveness of allowing research cooperation among companies in the same industry may create new support for antitrust policy legislation. Clearly, such legislation would provoke major political controversy.

A related aspect of industrial policy is the tendency of the United States to apply to U.S. companies operating abroad the same rules and constraints that apply inside the country.[1] The essentially adversarial relation between government and industry in the United States, whatever its historical justification or merits in spurring competition, often serves to put American companies abroad at a disadvantage in competing with companies directly supported and often subsidized by other governments. This is particularly relevant in high-technology industries, as companies in other countries are now able to compete as technological equals for the major new markets that will determine future economic strength. Obviously many complex and contentious factors will arise as this issue is addressed, but they *must* be discussed. The economic stakes are high.

The key determinant of America's competitive technological position is, of course, the strength and innovativeness of its high technology industries. Domestic science policy, including support for research, tax incentives, regulations, quality and adequacy of education, and other elements will crucially affect the economic scene in years to come. In addition, specific tax and other policies that bear directly on industry's decisions to carry out R&D either abroad or in the United States will require examination, though it should not be an automatic conclusion that overseas research by American firms is necessarily against U.S. interest. Overseas research can contribute directly to American R&D objectives, enhance the possibilities for large-scale cooperation (more on this below), and contribute to knowledge generally.

One of the greatest dangers of the current economic malaise in Western countries, coincident with serious competition from third world countries and from industrialized countries (especially Japan), is the possibility of a rise in protectionism—to preserve dying or inefficient industries. These industries may be failing for any number of reasons: increased labor costs relative to other countries; changes in cost of other factors of production, particularly for energy and resources; lower productivity; lagging innovation; inadequate industrial organization; and others. The temptation to respond politically to worsening domestic unemployment and its ancillary effects by preserving and protecting inefficient industries is very great, especially when a certain amount of implicit or informal protectionism is practiced by most countries in one way or another (hidden subsidies and biased regulations, for example).

The economic costs of a protectionist spiral among industrialized countries, and the consequent loss of incentives for innovation and support of R&D could be very great. In effect, protectionist measures are an alternative to R&D investment, at relatively low short-term cost and very high long-term cost: a poor bargain, but one likely to be proposed and actively sought by powerful forces in the near future.

One specific protection issue has emerged in recent years over the export of new technology which, it is argued, is tantamount to the export of American jobs as that technology becomes the basis of new competing industries. The argument is that technology developed in the United States is sold to others at a price that does not adequately reflect the true costs, or the broader effects on the United States of that sale. It is a disputed issue, not only with regard to the facts, but also whether this is a case in which the possible cure might be worse than the disease. For example, is the current government pressure to exclude foreign students and faculty from advanced integrated circuit research facilities at universities a wise policy? This is an issue likely to be more visible in the future.

Finally, under the heading of industrial policy the relationship between domestic regulatory policy to protect health and safety, and a nation's international economic position must be included. Already under intense scrutiny, this subject is certain to be the focus of important debate in the next five years. The basic concern is that unequal regulations from country to country can result in substantially different costs of production, thereby changing each nation's competitive position. That claim is made now with regard to American environmental and safety regulations that are presumed to have important effects on U.S. export potential. Equalizing regulations worldwide would be one way to manage the problem when it exists, but that would not always reflect different conditions in countries, different factors of production, or different values. Regulations can sometimes improve competitive position if the costs of compliance are higher in other countries competing in the same market. At times, regulations are simply a disguised trade barrier. Once again, the complexity of the situation does not allow simple judgments or generalizations. The positive current account balance of the United States in the last months of 1980, in the face of high energy costs and an improving U.S. dollar value would seem to belie the negative effects argument, but it is not known what the balance would have been in the absence of regulation. Moreover, the issue is usually cast not only in specific cost terms, but also with regard to the delays, uncertainties, and bureaucratic constraints imposed on industry by what is seen as a burgeoning regulatory environment.

The Reagan administration has indicated its intention to address this issue directly. It is hoped that sound data and analysis will support any actions taken.

Cooperation Scientific and technological cooperation among Western technologically advanced countries is not rare. When compared with the scale of investments in R&D and the common goals of Western countries, however, the number of cooperative projects, especially in technological development, is rather small. The explanations are obvious: difficulties encountered in organizing cooperation; concern over losing a competitive position; and, most important, the basically domestic orientation of most governments. Meshing of programs, objectives, budgets, and people is much more complex than when carried out within one country.

Current economic needs and constraints may now put cooperation, especially technological cooperation, much higher on the agenda. Industrial countries are all in need of technological progress to meet their social, political, and economic requirements, at the very time when the economic situation that created these requirements also serves to place severe budgetary constraints on national R&D expenditures.

Today's nearly equal competence in science and technology among countries also means that a given project is likely to benefit from larger application of resources. In some cases, participation by more than one country may be necessary to attain a critical size. The massive investments required in many fields of central and growing importance, especially energy, also make the possibilities of cooperation to reduce the drain on national budgets particularly attractive.

The difficulties and costs of cooperation cannot be ignored:

- inherent difficulties of meshing disparate bureaucracies;
- delays in reaching decisions among differing political and legal systems;
- complications of varying decision processes, priorities, and competencies;
- cost of international bureaucracy;
- the danger of political inertia, which makes projects hard to start, but even harder to stop;
- the possibility of drains on research budgets because of international commitments;
- the tendency to undertake internationally only low priority projects;
- the apparent conflict between cooperation and improving a nation's competitive position.

Successful cooperation also requires reliable partners. The record of the United States in modifying or abrogating agreements makes future agreements harder to reach. Most recently, the proposal to cancel the coal liquefaction development project with Japan and Germany, and to withdraw from the International Institute of Applied Systems Analysis have damaged our reputation as reliable partners.

Difficulties are formidable but the potential benefits are also formidable. Successful examples of cooperation (airbus, International Energy Agency projects, coal liquefaction until this year) demonstrate it can be done. Greater willingness of the U.S. bureaucracy to look outside the United States and recognize the competence and knowledge available elsewhere, and the greater experience the bureaucracy would attain through making the effort, would be substantial additional benefits of accelerating the pace of international cooperation. The forms of cooperation (bilateral, trilateral, Organization for Economic Cooperation and Development—OECD) all need to be examined for each case, though the OECD is the logical organization in which to lay the groundwork and establish a design among Western countries. Increased attention to genuine international technological cooperation ought to be an important task of the 1980s.

North/South Science and Technology Issues

The differential ability to acquire and exploit technology is a major determinant of the strikingly different economic situations and prospects of nations of the North and South, and one of the prime sources of the political

84

disputes among them. Differences in technological capability, however, are potential levers for constructive assistance and cooperation. Can this nation grasp those opportunities, which play to its strongest suit—its technological strength?[2]

The fate of developing countries in economic, political, and military terms in coming years will have a great deal to do with international political stability, and with the security of all nations, not the least the United States. It is reasonable to forecast that international turbulence will be centered in the developing world. That estimate is reflected in U.S. military and foreign policies. It is much less evident in official economic policies—the U.S commitment to economic assistance is scandalously low relative to that of other industrialized countries. The various reasons for U.S. indifference and frequent opposition to foreign assistance cannot be usefully probed here. However, the central nature of technology in development does provide a focus for exploring how to maximize the U.S. role, whatever the aggregate scale of assistance, and for highlighting some of the particular issues within specific fields (such as agriculture and population) which need to be confronted.

Economic growth, political stability, and a working economy in a developing country (with important effects on agricultural production, resource availability, reduction in fertility, and markets for American goods) can all be advanced by external assistance from the United States. It is in our national self-interest to provide this assistance. This is not to deny that the more economically advanced a developing country becomes, the more competitive it is with the United States; nor is it to deny that political stability does not automatically follow growth, or that the political objectives of developing countries may differ from our own. But U.S. self-interest is better served by the steady advancement of developing countries than by lack of progress. Whether or not economic assistance to developing countries is high on the U.S. agenda at the moment, there is a substantial probability that it will be forced there through political or economic crises, or national calamities such as widespread drought.

Technology Policy to Developing Countries It is no longer necessary to justify the importance of technology in development. Technology is essential to management of the problems of agriculture, health, environment, industrialization, population, energy, and most other aspects of a modernizing society, and is recognized (sometimes overemphasized) in most developing countries to be essential. The United States, whatever its relative decline in technological leadership, is still the world's strongest technological nation, with a broad and flexible education and research establishment.

The technological capability of most developing countries is steadily improving. Nevertheless, most research is carried out in the developed countries either for military purposes or for the domestic problems of those countries. Perhaps no more than 5 percent of global R&D can be said to be devoted exclusively to problems of development. In a setting in which industrialized nations have such a stake in economic growth and elimination of poverty in the developing world, it makes little sense to devote so little scientific and technological effort to problems that are peculiarly those of developing countries.

Much of this R&D cannot and should not be done in industrialized countries, for practical as well as philosophical and political reasons. To be effective, to work on the right problems, to be sensitive to local needs and preferences, to produce solutions that fit and are likely to be adopted, to keep up with and adapt technology—all require R&D defined and carried out locally. In turn, this implies attention to the building of the scientific and technological infrastructure in developing countries.

This does not mean, however, that all research relevant to developing countries needs must be carried out locally. Many areas of basic research can more effectively be done in existing laboratories; many problems are generic and can be more quickly investigated in experienced laboratories with resources and skills already deployed; many technological problems require general solutions before locally adapted applications are possible. Perhaps most important is finding ways to elicit commitments from scientists and engineers in industrialized countries to work on problems of development in a sustained way that allows cumulative benefits and continuous attention. Long-term availability of financial resources is essential, not only to make such commitment possible, but also to make it respectable in the eyes of disciplinary peers.

Transfer of existing technology to developing countries is no longer seen as an adequate alternative. Experience shows that such transfer, especially of public technologies of health and agriculture, is inefficient or inappropriate without adequate receptors to choose, adapt, finance, and develop knowledge to fit local environments and needs. Technology requires adaptation to a unique social, economic, and political as well as technical environment. Also, it tends to change that environment, often quite rapidly, so that mutual adaptation of technology and environment is a continuing and dynamic process.

Relations of developing countries with multinational corporations also require local capability. The bulk of industrial technology is transferred to developing countries through private investment by international firms. To work effectively with technologically advanced companies, without losing control of the resulting development or being exploited economically, presupposes the ability to set realistic objectives, negotiate contracts, weigh often esoteric choices, and in general be fully aware of technological and economic options.

Thus, a significant and growing indigenous capability in developing countries is required. And, it must embrace basic science as well as technology, for without the insight and self-confidence created by an indigenous scientific community, a developing country will lack the ability to control its own development. In short, what is required is greater allocation of research resources to development problems in advanced countries, especially in the United States, and the building and strengthening of indigenous capability in developing countries.

To date, the ability of the United States to help in either of these efforts has been seriously limited, because of the low level of resources allocated, and because of the institutional and policy constraints that deter or prevent effective commitment of scientific and technological resources for other than domestic purposes. At present, essentially all research devoted to problems of developing countries must come from the foreign assistance budget either spent directly by the Agency for International Development (AID), or through transfer to other U.S. government departments and agencies. With minor exceptions, departments and agencies are prohibited by their legislative charters or by the budget process from spending any of their own funds on objectives other than domestic ones. Thus in an overall federal R&D budget well in excess of $35 billion, the total allocated for objectives directly related to developing countries, is on the order of $100 million, or one-third of 1 percent.[3]

The result is not only very limited in terms of R&D output; it also means that the competence of the U.S. government's technical agencies is barely tapped on issues to which they could significantly contribute. When all funds come by transfer from other agencies, there is no incentive to build staff or agency commitment, to work on these issues with their congressional committees and university or industry constituents, or even to know through experience how they can contribute.

The rationale for these legislative restrictions and for budget compartmentalization stems from the early history of the creation of cabinet departments and agencies, and from natural management principles of tying program objectives tightly to appropriate funding sources. The trouble is that as foreign and domestic issues have become more closely intertwined, corresponding reflection in the allocation of resources has not taken place. And the rigid budget compartmentalization does not take into account the often mixed purposes (combining technological and development assistance goals) of many possible programs.

The implications of these institutional restraints go farther. Astonishingly, the United States has no governmental instrument for cooperation with other countries, unless that cooperation can be defined either as scientifically competitive with domestic research and development, or as foreign aid for the poorest of countries. Thus, the United States cannot respond to those developing countries that have graduated from the poorest status, the very countries with developing science and technology capabilities best able to make use of cooperation with the United States, though not yet able to compete at the scientific frontiers. These countries have the greatest interest in substantive cooperation (often without any transfer of dollars), and are in the best position to begin solving their own problems as well as assisting in attacking global problems.

In fact, in recent years, the United States has undertaken rather substantial efforts at developing bilateral science and technology cooperation with these countries. Those initiatives have had to be taken primarily at the White House level directly, with major problems of planning and implementation. And now, at least some bilateral agreements that already have been negotiated may be abandoned as a result of large, targeted budget reductions.

The opportunities to use America's strength in science and technology in cooperation with other countries to further U.S. objectives (political and economic as well as scientific) are likely to grow in the coming years. The absence of an adequate institution and policy process to plan and fund these programs, and to engage the competence of the American scientific enterprise, both governmental and private, will be an important issue that will have to be confronted. The Institute for Scientific and Technological Cooperation (ISTC), which was proposed by the administration in 1978 and authorized but not funded by Congress, was designed to correct some of these institutional and process deficiencies.

Food and Agriculture Some issues within the context of North/South relations stand out in their importance and in the likelihood they will or should be the focus of much greater attention in the next quinquennium in the United States. One of these is food and agriculture, because of its fundamental nature in the development process and the great concern that increases in agricultural productivity will not keep pace with the growth of population that already includes several hundreds of millions chronically malnourished.[4] It is estimated that food production must increase at least 3–4 percent per year if significant improvement is to occur by the end of the century.[5]

The United States has a unique role to play because of its unparalleled agricultural production, as well as its R&D capabilities. For the reasons cited earlier, however, much of the necessary R&D and experimentation must be carried out in the countries trying to improve their own agricultural enterprises. This implies building greater indigenous capabilities than now exist, and also strengthening and expanding the enormously successful international agriculture research centers that have been primarily oriented to, and staffed by, developing countries. The recent moves to devote more of the resources of these centers to the applied problems of improving agriculture (low-cost technologies, water conservation, etc.) are much to be applauded. The international centers must not be seen as alternatives to individual country capacity, but as necessary complements to allow some economies of scale, to focus resources on generic problems, and to provide an essential psychological tie to a world community for a sometimes isolated scientist in a poor country.

The U.S. research community could play a substantial role, larger than is at present likely. One impediment is the budgetary process, cited earlier, that bars the Department of Agriculture from effectively committing its own funds for agricultural problems not seen as domestic.

Another is the organization of agricultural research in the United States that is essentially a state-based structure without the extensive tools for central planning or quality control. That makes it difficult to ensure the essential quality of the entire agricultural R&D effort, to build competence in areas of study not peculiar to the United States, or to enable effective planned connections to be established between developing countries and the United States on agricultural R&D on any satisfactory scale.

It is also important to note that improvement in agricultural productivity is not dependent solely on advances in traditional areas of agriculture. Water conservation, climate, energy, pest control, and low-cost technology, and the social sciences related to agricultural economics, innovation, application and distribution, are, inter alia, of equal importance. The agricultural research agenda must include those areas as well.

Population Although fertility has declined in recent years, growth projections remain high enough to cause serious problems of starvation, economic stagnation, and political unrest.[6] The international system has only begun to feel the effects of forced or voluntary migration across borders, which is likely to become a major cause of international political instability in the future; in addition, there is the already evident internal instability that arises from urban migration, un- or underemployment, lack of adequate food and sanitation, and serious health problems.

Science and technology cannot solve the population problem, but they can provide the necessary tools for public policy. In particular, more research is needed to provide low-cost contraceptive technologies (especially including male contraceptives), and to increase our understanding of the social determinants of effective family planning policy. Fertility decline is so closely related to other aspects of development, particularly health, food, sanitation, transportation, and communications, that in a sense all technological research can contribute indirectly or directly to the population problem.

In population-related (and health-related) subjects, we find a special variant of the domestic orientation of U.S. institutions. Health and safety regulation of drugs in the United States is based on risk-benefit criteria keyed to the United States. Thus, proposed contraceptive drugs are evaluated for safety based on the risks of health side-effects in the U.S. environment, when the risks and benefits are likely to be quite different in another country. In some cases, American pharmaceutical companies are deterred from developing a drug at all, since the benefits of protecting against some diseases (schistosomiasis, for example) are so low in the United States that any risk of side-effects would overwhelm potential benefits, while in another country the benefits would greatly outweigh the risks.

The reverse side of the coin is the stringent testing regulations in the United States that have led some companies to test drugs for safety in other countries, in effect using their people as guinea pigs for the U.S. market.

Neither situation is tenable. Some means must be found of internationalizing drug evaluation, as it would not be appropriate to expect the Food and Drug Administration, for example, to institute its own criteria for evaluating drugs for foreign applications that would be different from criteria for U.S. application.

The general problem of encouraging greater commitment of U.S. scientific and technological attention, whether in government, industry, or university, to population- and health-related issues should be an important issue in the near future.

TRANSBORDER ISSUES

A series of transborder and global science and technology issues will be important elements of the international security picture in the next five years, though the separation of these from "economic" issues is rather arbitrary. The importance of environmental, ocean, resource, and energy issues will be largely in their economic and ultimately political effects, as is the case for those just discussed.

Resources and Energy

In the short term, the major issues related to security, resources, and energy have to do with supply interruption engendered by political action, and secondarily, the economic terms on which resources are made available to industrialized societies.[7]

A major political phenomenon of recent years is the assertion of the right of absolute sovereignty over natural resources. It is a natural concomitant of a nation state system, but has not before been sanctified as it is today. The growing dependence of industrialized societies on resources under the control of others, particularly developing countries, creates major dependency relations, many fraught with great uncertainty and danger for international stability.

The dangers come not only from the threat of supply disruption, or of sudden dramatic increases in the cost of the resources, but also from the second-order strains created among industrial countries whose disparate dependence on resources from abroad may lead to major and disruptive foreign policy differences. The much greater dependence of Japan and Continental Europe than the U.S. on Middle East oil, or the differential dependence on South African resources could lead to serious conflicts of interest over Middle East, or African, or Soviet policy.

Though the world is painfully conscious of the political restrictions oil-rich developing countries sometimes place on resources, these countries are not the only ones to do so. Canada and Australia have both restricted export of uranium ore on nonproliferation grounds, and the United States severely restricts export of enriched uranium on the basis of specific political considerations. Moreover, the United States embargoed soybean exports for a short time in 1974 to stabilize domestic prices, and has embargoed the sale of grain and high technology to the Soviet Union in political protest to the Afghanistan invasion. A cabinet member of the Reagan administration in his first public statement spoke of using U.S. food exports as a foreign policy "weapon" (later changed to "tool").[8]

These consequences of resource dependency and of unequal distribution are all political and economic in character. The issues arising in the near future will be concerned with distribution and availability, but not with depletion. In the long-term, the adequacy of resources will be determined by economic, not geological, phenomena,[9] and there is no reason to doubt that the industrial system could cope with long-term changes in the price and availability of materials and energy.

Short-term vulnerabilities must be met with measures that are largely outside the realm of science and technology directly: stockpiling, political negotiations, pooling arrangements in time of crisis, and so on. Conceivably, new R&D for resource exploration, or exploitation of deep seabed minerals, could change U.S. dependency on foreign resources, but this is unlikely in a five-year time horizon.

In the longer term, science and technology have major roles to play in the development of substitutes; in expanding knowledge of resource exploration, recovery, processing, and use; and more generally in contributing to innovation and productivity in the nation's industrial plant (both to improve efficiency of use of materials and fuels, and to generate the export earnings necessary to pay for imports). The long lead times inherent in reaching these objectives mandate early commitment of R&D to these tasks.

The changing price and availability of materials and energy may change critically the comparative advantage of some American industries. The adjustments necessary to allow the orderly decline of those industries will themselves set up serious political and economic strains.

The need for R&D in the resource area is coupled with an inadequate understanding, both in the United States and globally,[10] of certain areas: geological deposition of minerals; the exploration process; and the impact of the changing industrial structure in minerals on the flow of mineral supplies.[11]

These tasks will require reinvigoration of concerned government agencies, especially the Bureau of Mines and Geological Survey, and may also require a new institutional means to develop an objective, credible data base (technical and economic) for resource-related decisions. In addition, coordination of policymaking must be improved to avoid conflicting policies carried out by individual agencies which are not aware of the activities of other agencies.

Environment and Global Commons

Closely related to resource and energy issues are those involving transborder environmental questions, and more general global issues of the environment: atmosphere, oceans, and outer space.

Our national activities have effects beyond borders and, in some cases, on a global scale. Transborder pollution has already become an important issue in many areas of the world, with some progress in the last decade, particularly in melding environmental policies, in reaching international agreements, or dealing with the traditional problem of the global commons. The issues are likely to become more severe, however, and often will take on the cast of zero-sum games.

The worldwide recession and the rise in energy prices raise the indirect costs of coping with environmental degradation, and make it more difficult politically to restrict activities whose harmful effects fall across the border. The standard problem of reflecting full costs in a production process is exacerbated when the externalities are felt outside a national economy. Issues associated with acid rain, water pollution, forest degradation, and others will become more contentious internationally in the next decade.

The depressed economic situation will also lead to greater resistance to domestic environmental regulation if that is assumed to affect adversely the international competitive position of a nation's goods. As noted earlier, it is not always appropriate to call for common environmental standards in all nations, and even when it is, it is not clear they can be successfully negotiated. Thus, the costs and bases for domestic environmental regulations are likely to be difficult issues because of their international implications.

Some long-term issues may become clearer in the next few years as research increases understanding of important global systems. In particular, CO_2 buildup and NO_X in the atmosphere may be better understood along with their global economic implications and potential ways of controlling them. Unprecedented disputes could arise over such issues, with important changes in the status of individual nations, as some benefit—say through improved agricultural conditions—and others are hurt—for example, if the costs of environmental controls fall more heavily on them. It is unlikely that these issues will come to a head in a few years, but the debate could be far advanced.

Exploitation of global commons, especially the oceans and outer space, is likely to proceed during the coming decade. The Law of the Seas negotiation, which proposed a new international institution responsible for overseeing the mining of the resources of the seabed, appeared to be almost completed, though the position of the United States is now in doubt. Many aspects of that institution would be novel, in particular the assigning of some of the benefits of mining to developing countries. The detailed questions of implementation would be left to the interim arrangements following the completion of the treaty and ultimately to the new authority. Some serious disputes are inevitable, with regard to the mining itself, the operation of the authority, and the unprecedented provisions for transfer of technology in the draft treaty.[12] Certainly, if there is no treaty, a variety of ocean issues—navigation, fishing, oil exploration, research, as well as mining, may become the source of serious dispute.

In space applications controversy may arise over geostationary orbit allocations, but more likely will be controversy over the international efforts to manage and control space technology systems such as Landsat. This earth resource surveillance system has been until now an experimental American monopoly, but as it moves to operational status, many questions will become more pressing. Who owns the information in a world in which sovereignty of resources has been zealously asserted? Should the output be available to anyone who asks for it? What rights do nations have for unilateral surveillance of another country's resources? What are the security implications of the high resolution that will now be built into the system? Who should manage the system, and determine its technical characteristics? What are the economic and political implications of greater knowledge of resource endowments, of more accurate annual predictions of agricultural production domestically and internationally? Undoubtedly, these issues will soon become more prominent on the international political agenda.

Interaction of National Technological Systems

Many national systems—aircraft, communications, weather observation, finance, banking, postal—are basically information systems which require interaction with counterparts in other nations. The explosive development of information technology systems has begun to cause serious strains, and is likely to be an even larger cause of strain in the coming years.

Traditional differences between fields break down (for example, communications versus data flows, postal versus electronic mail, information versus banking), and the economic calculus of benefits and costs changes perceptibly. Controversies arise over privacy of information, access to information within nations, the role of central computer banks, the transnational nature of economies of scale, and related issues. In the face of U.S. dominance of technology, other Western countries are wary of allowing unfettered development that undermines their competitive position; the Soviet Union and its allies worry because control of information is vital to its political system; the developing countries worry that the loss of control over information will threaten their independence.

The dynamic nature of the growth of this technology, and its base in the private sector in the United States, makes this a particularly difficult issue in which to anticipate implications, much less develop clear international policies and conduct negotiations. It is certain to appear significantly on the international agenda in the 1980s.

NATIONAL SECURITY

Science and technology have been central factors in the evolution of weapons and military systems in this century. They have altered drastically not only the nature and scale of hostilities, but the very meaning of strategic war as an option to achieve national objectives. The strength and productivity of a nation's advanced technological community have become major elements in any geopolitical calculation. Massive support for security-related R&D has, in turn, changed science, technology, and the university.

The application of science to national security shows no sign of abatement. In fact, a new round of major commitments to large-scale strategic systems is in the offing, turning the ratchet one more notch in a search for security that seems steadily receding into the future.

In the context of this paper, only a few general issues in this area can be briefly touched upon; clearly it is an enormous subject that is itself the subject of a large literature.[13]

One controversy concerns whether the constant search for more technologically advanced weapons systems in fact contributes to the nation's (or the world's) security. Whatever the views of the causes of the arms race between the Soviet Union and the United States, or the current state of relations between the super powers, new weapons systems often make the arms balance more precarious, more vulnerable to preemptive action rather than contributing to stability. This may continue, and perhaps worsen, as capabilities are pursued that threaten concealment of weapons systems, give greater premium to surprise, and make it harder to know whether missiles contain one or many independent warheads. Developments in conventional weapons, moving rapidly, may also change the nature of "local" war, leading to greater instability among developing countries as one or another believes it has the capability for rapid strike and victory.

No simple solutions exist. It is easy in rhetoric to call, for example, for more attention to military and related systems that contribute to greater stability and less uncertainty and threat: adequate conventional ground forces; improved command, control, and communications in a hair-trigger weapons environment; greater commitment to developing arms control agreements; more attention to "hot-line" communication capability; less emphasis on strategic weapons that pose a first-strike threat in favor of those with clear survivability; and others. Each has its ambiguities, however, and there is no agreement on what is required for security, or even for greater stability.

The fact of the matter is that science and technology are most likely to continue to alter military systems. The effects of these changes cannot always be anticipated. One of the objectives of arms control is to bring the situation under greater control; but even if one were optimistic about SALT II, agreements of this sort deal only with existing or planned technology. They do not deal with the possibility of new weapons systems or unanticipated capabilities created by further research.

Our knowledge of "threat systems," the involvement of the scientific and technological community in strategic debates, the public perceptions of military and strategic affairs are all inadequate. The once substantial public role of scientists and engineers in strategic policy deliberations, for example, has been greatly reduced, and the public inputs to arms control and weapons debates have suffered. This is illustrated by the spectacle of the stagnation of the SALT II agreement in the U.S. Senate over essentially extraneous issues.

Some argue that the whole framework of the strategic debate has been rendered inadequate.[14] They call for emergence of a new paradigm, a new discipline of conflict studies, and assign the scientific community special responsibility in bringing this about. The argument of the inadequate framework of debate is persuasive, although the path for achieving a new paradigm is hard to discern in practical terms.

The scientific and engineering communities have special but more traditional responsibilities within the existing framework particularly because of the esoteric technical aspects of the issues. The relative neglect of these responsibilities in recent years must be reversed. New programs such as arms control fellowships in the National Academy of Sciences and a concomitant program of studies are to be applauded, and similar initiatives in other scientific organizations are to be encouraged. In all these efforts, however, it is important to recognize that the issues themselves are never purely technical. Real participation involves a commitment to master the political, economic, and related aspects, which will eventually determine the outcome.

The quality of debate needs to be improved in the public sector as well as in the scientific communities. Better information, and greater resources, public and private, committed to the analytical area are badly needed. The momentum of a defense budget close to $200 billion requires open debate of the purposes, details, and implications of that budget. In turn, more funding is required to produce information and analysis to make public debate possible. The congressional commission to study the establishment of a National Academy of Peace and Conflict Resolution presumably has the same goal.[15]

One aspect of the role of science and technology in weapons development is peculiarly troubling. Much of the initial development of ideas for new technology—ideas that may later be revolutionary in military terms—occurs in the laboratory at a very early stage, without military applications in mind, and often without military funding. This dynamic of the research process leads to instability, both in weapons development and in the long-term viability of arms control agreements.

Little can be done about this now, although ultimately ways of bringing R&D within the scope of arms control agreements must be considered. One aspect, somewhat farther along the R&D chain, does deserve institutional attention, however.

Proposals for new weapons development are, in their early stages, often made at low levels in the bureaucracy, with relatively little R&D funding required. At these levels, choices tend to be made on strictly technical grounds, with little consideration of their ultimate effect on relevant arms control objectives. The situation is repeated at higher levels as well, so that it is not uncommon for the government to be faced with mature weapons designs creating major new foreign policy problems that might have been avoided or eased if some alternative technical options had been chosen instead.

It is very difficult to deal with this issue in the bureaucracy, since the organization of government serves to create bureaucracies with compartmentalized objectives and few or negative incentives to introduce considerations for which they are not responsible. An attempt to introduce nonproliferation considerations into planning for nuclear reactor R&D, through participation of a State Department representative in the setting of objectives in the Department of Energy, has apparently had some limited success, and deserves evaluation.

In its most general formulation, this task can be stated as the need to include, in defense R&D planning and management, the evaluation of broader effects of the intended results of research. The objective is an important one and ought to be the focus of further experimentation.

Other aspects of science, technology, and security are also troubling; some because of the effects on nonmilitary areas. The sharp increase in defense spending proposed by the administration will have important effects on the civilian sector, not only in the obvious impact on the budget. Engineers, already in short supply, will be siphoned off in larger numbers to defense industry, exacerbating the shortage in consumer goods industries, and likely worsening the nation's competitive position. It will also tend to stimulate even more the momentum of scientific and technological change applied to military hardware, since the level of R&D, and the ideas for new applications, will be fueled by the larger cadre of scientists and engineers.

The increase in defense spending may also affect the nation's universities, as they become concerned about the almost direct military application of basic research. Signs of that are already evident in cryptological applications of theoretical mathematics, which have led to a kind of voluntary censorship.[16]

Lastly, it must be noted that the Soviet Union has demonstrated its competence to engage the United States in a high-technology arms race. Its technology may not be as refined, but its greater commitment of resources to defense expenditures is presumed by many to be likely to give the Soviets an edge of some sort over the United States in the latter part of this decade.

Whether this prediction is accurate or not, its anticipation has already fueled a massive new U.S. defense increase. One can only observe that a continued search for strategic superiority over a determined opponent is the search for a chimera that can only distract from the real quest for security.

EAST/WEST TRANSFER OF TECHNOLOGY

Another issue which is likely to be of considerable moment in the next five years is the concern over the transfer of technology to the Eastern bloc that could enhance the military capability of the Soviet Union and its allies.[17]

This is an issue with a history stemming from the advent of the cold war, and with recent attention as a result of the embargo on high technology imposed in response to the Soviet invasion of Afghanistan. It is bedeviled by controversy between the United States and its NATO allies over the costs and benefits of the policy, by uncertainty over the military relevance of some "dual use" technologies, by sharp differences of view within the American government, by differences of philosophy over the value of denial in terms of its actual effects, and by differences with industry over enforcement policy.

There is little question about the importance of embargoing specific advanced military technology. Moving from technology with direct military applications, however, quickly leads to gray areas, with uncertainty over military relevance, over availability from uncontrolled sources, or even of whether denial is in Western interests. Should the West, for example, encourage the Soviet Union to improve its ability to explore and recover its vast oil deposits?

Many more specifically technological questions arise, however: How is technology actually transferred and adopted? What is the real potential of diverting a piece of hardware from a peaceful to a military application? And what actual difference would it make? Is reverse engineering of a piece of equipment possible? At what cost? On what time scale? How long will it take for a particular technology to be developed?

All too often, the debate over technology export controls is characterized not only by political naiveté, as though it is simple to control the movement of technological information, but also by lack of understanding of technological realities. The importance of the issue, and its potential for damaging the West politically and economically, will require effective integration of the scientific and technological aspects in the policy debates.

INSTITUTIONS AND POLICY PROCESS

Several themes run through the issue areas discussed above that bear directly on institutional and process problems of the United States in relation to the international consequences and use of science and technology. The most common theme is that the international dimension of policy is inadequately reflected in government policymaking, and that the formal institutions of government militate against more effective recognition of international issues. Though this observation may be valid for many of the responsibilities of government, it is particularly, and surprisingly, intensive in science and technology matters.

Other themes that emerge relate to the need for more effective integration of scientific and technological aspects in many policy areas, including more mechanisms for effective analysis and anticipation of future implications of science and technology; and the need for new national and international institutions. Some comments on each are in order.

INTERNATIONAL DIMENSION IN POLICY

The history, geography, and rich resources of the United States all led naturally to a system dominated in institutional form and political organization by domestic considerations. Adaptation of the system to its new global role, and to its new dependency on others, has been slow and halting, notwithstanding the enormous sums of public money allocated for this adaptation. At the detailed level of decision making—budget decisions, negotiations with the Congress or with the Office of Management and Budget, setting technical objectives—the traditional pressures dominate.

One of the most significant ways in which this situation affects the involvement of science and technology with international matters has to do with developing countries. The national resources devoted to R&D on development problems are pitifully small, yet the U.S. government lacks an effective instrument for cooperating with that large number of increasingly important nations neither poor enough to be eligible for direct assistance, nor sufficiently advanced scientifically to be competitive with domestic research. A new institution—the Institute for Scientific and Technological Cooperation—was proposed in 1978, authorized in 1979, and ultimately left unfunded by the Congress. Something to serve the same functions, whatever the form, is required.

But the problem is not simply a new institution. The need is to tap more effectively the scientific and technological resources of the government housed in the functional departments and agencies, and to enlist their R&D clients in the nation at large. A single new agency cannot accomplish that task alone, though it might provide the leadership for much larger changes. Rather, a means must be found for allowing departments and agencies to allocate resources directly for cooperation with other nations and to carry out R&D on problems that are not "American" problems, when such activities are in the national interest. At present, legal authorization or executive budget policy effectively prevent such allocation except under difficult arrangements, sometimes sub-rosa, and almost always ad hoc.

The problem is not primarily legal, as Congress can change the relevant laws, and has done so for some agencies. The problem is largely one of efficient budgetary management. The Office of Management and Budget argues, with considerable justification, that it is difficult to maintain discipline in a budget if fuzzy arguments of "foreign policy interest" have to be given weight in ranking proposed programs, or if budgets to serve development assistance objectives crop up in a score of federal agencies.

Yet, the answer must surely be more creative than simply to rule out such programs. One possibility, for example, would be to create a development budget that crosses departmental lines and forces a degree of budgetary discipline that cuts across agencies and agency budgets.

Departments and agencies would be allowed, with congressional concurrence, to budget some of their own funds for R&D, but those projects would have to be compared not only with proposals within the department, but also with proposals of other agencies. Similarly, for those proposed programs that have mixed foreign policy (other than development) and scientific objectives, a cross-agency evaluation of foreign policy could exert the necessary budget discipline. Although difficult to administer and subject to its own bureaucratic pitfalls (the temptation for playing budgetary games and the difficulty of ranking according to foreign policy criteria), this or something like it requires experimentation.

In another area, ways must be found domestically or internationally to deal with situations in which apparently domestic regulations directly impinge on other countries or significantly affect a country's international trade position. For some situations, the answer may have to be regulatory machinery within existing or new international organizations. With regard to trade regulation, more impetus will have to be given to the move to analyze the broader economic effects of proposed regulations before the regulations are approved.

International cooperation with advanced countries also deserves more emphasis in the changing climate of cost and relative competence in science and technology. But this change in emphasis will not happen naturally in the American system, again because of the built-in focus on domestic problems and pressures. This problem of focus is exacerbated by the restrictions imposed by the Office of Management and Budget on foreign travel, and the suspicion in Congress that foreign travel by "domestic" agency personnel simply implies junkets.

The blurring of domestic and international affairs is real. Government at all levels must become aware of and adapt to their ineradicable intertwining. It is not a matter of simply creating an international office in an agency. All have such offices, which more often than not are weak and removed from the core of the agency's interests.

Rather, it is a matter of infusing the whole government with policies, institutions, and rhetoric to make possible a gradual change of attitude that conforms to today's and tomorrow's reality. The Congress must also be no small part of that change, and ought to be forcing the Executive Branch to recognize what is needed.

INTEGRATION OF SCIENCE AND TECHNOLOGY IN POLICY

The problems of scientific and technological planning are particularly severe, and pose major problems of governance in a technological age. There are many aspects: how to represent scientific and technological information and uncertainty adequately in the policy process; how to plan for effects of science and technology not only uncertain, but possibly seen too late to alter once the effects are in evidence; how to estimate risks and benefits which fall unequally within a society or internationally, with interested people and nations often not represented in the policy process; how to deal with issues in which the relevant information is under the monopoly of one segment of society, or of one government; and a host of other issues.

No single solution is adequate. Like all problems of governance, these problems are not solvable—all that is possible is amelioration or improvement. However, these are difficulties that directly involve understanding of science and technology, and thus require not only greater participation of scientists and engineers, but also more means for making credible analyses available to the public, and ways of drawing the public into the debates. Participation alone, of course, is not enough. Scientists and engineers do not have, on the basis of their professional training, superior credentials for making policy decisions. They are no more free of bias than are other segments of society. Participation by the scientific and technological communities implies a commitment to understand the interaction between science and technology and the broader aspects of policy, and a commitment of time that makes such understanding possible. A technocratic approach to the making of policy is not an improvement over the present situation.

One of the effects of science and technology on both national and international affairs is to make the future much more relevant to the present than in earlier periods of human history. To an unprecedented degree, today's policy must be made in the light of future developments, particularly in science and technology themselves, or in the side effects of increasingly technological societies. The importance of more efforts at credible, objective anticipation of the future is obvious.

INTERNATIONAL ORGANIZATIONS AND STRUCTURE

The need for new international instruments, or for modifying existing ones was mentioned briefly in a few subjects—drug regulation, ocean mining, space applications—but was not emphasized. The questions associated with international political machinery, particularly machinery designed to deal with requirements growing out of science and technology, are many and complex.

The products of science and technology increasingly create new issues and force traditional domestic issues into the international environment. Unfortunately, existing international organizations charged with dealing with those issues are often inadequate. Most global organizations are now politicized along North/South lines, and more efficient regional or smaller alternatives do not represent all interested parties. As representation in organizations broadens, technical efficiency tends to decrease.[18]

This situation is unlikely to reach crisis form within a few years, but in it are the seeds of major confrontation. These seeds could mature quickly, if current budgetary reductions drastically reduce U.S. presence in international organizations. The adequacy of international political machinery is likely to be a fundamental question of international security. So many of the functions the world (and the United States) depends on—communications, transport, nuclear materials control, resource information, health, agriculture, ocean minerals, to say nothing of international financing and lending—will fall increasingly under the auspices of international organizations. Many of the issues involve developing countries, but others involve conflicts of interest among Western industrial countries, or East/West controversies.

It is not a matter of indifference whether the organizations exist or work. The functions they perform must be carried out in some way by an organization, or by a limited number of countries, or by a country acting on its own. The ultimate character of the international system and the place of the United States in it may in large measure be determined by whether these international tasks are carried out through organizations with broad participation, but so designed as to allow reasonable efficiency, or by default are managed by efficient but limited groups of wealthy countries.

CONCLUSION

It may not be too far wrong to characterize this last issue, and all that have been touched on in this paper, as fundamental choices in the international system between efficiency and equity, and between hegemony and consensus. Those are sufficient for any policy agenda.

NOTES AND REFERENCES

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2. See the paper by Charles Weiss on pp. 475–490 of this volume.

3. "Development Issues," 1981 Annual Report of the Chairman of the Development Coordination Committee, U.S. IDCA.

4. The paper by Sylvan Wittwer in this volume (pp. 491–502) discusses this issue.

5. Ibid., p. 492.

6. The paper by Michael Teitelbaum, pp. 503–511 of this volume, is devoted to the population problem in substantial detail.

7. The paper by William Vogely on pp. 513–522 of this volume deals with resource issues in detail.

8. *New York Times* (27 December 1980).

9. See p. 518 of the paper by Vogely in this volume.

10. Ibid., p. 521.

11. Ibid.

12. Law of the Sea draft treaty, United States Delegation Report, "Resumed Ninth Session of the Third United Nations Conference on the Law of the Sea" (Geneva: 28 July-29 August 1980).

13. The paper by Kenneth Boulding on pp. 523–531 is devoted to one aspect of the subject.

14. Ibid.

15. Ibid., p. 527.

16. *Science*, vol. 211 (20 February 1981), p. 797.

17. Office of Technology Assessment, *Technology and East-West Trade* (Washington, D.C.: U.S. Government Printing Office, 1979).

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United States Policy Toward Scientific and Technological Development in the Developing Countries: The Case for Mutual Benefit

*Charles Weiss, Jr.**

INTRODUCTION

As the United States enters the 1980s, its foreign policy objectives are being reexamined to fit a changed world and a new political climate. These objectives must adapt to the greatly increased economic strength of Europe and Japan, to soaring energy costs coupled with threats of the cut-off of energy supplies, and to the growing military, financial, and political power of the developing world. Pressures for economic nationalism in the form of barriers to imports, exports, and the flow of labor and technology, are intensifying throughout the globe.

U.S. technology, while still the envy of the world, no longer enjoys undisputed preeminence. Difficulties in the automobile industry are only the most dramatic manifestation of the deterioration of American competitiveness in relatively labor-intensive manufactures. The latest reexaminations of our standing in the international marketplace reflect concern that the United States may even be losing its competitive edge in electronics, hitherto one of its greatest strengths.

The world faces a future quite different from that optimistically projected in earlier decades. International inflation has resisted the prescriptions of a substantial range of schools of economic thought. The federal government's *Global 2000* study reiterates the conclusion of previous world models that the beginning of the twenty-first century will probably see a 50 percent increase in world population, a doubling of real food prices, further increases in the real price of energy, world-wide loss of forests and genetic heritage, and substantial pressure on the world's water resources.[1] For the first time, in the words of John Fairbank, the nations of the world are in trouble together.[2]

The developing countries (also known as "less developed countries" or "LDCs") are increasingly important to the United States. They are a source of oil and minerals, a market for exports now more important than Europe and Japan, and a source of immigration, both legal and illegal. That their political instability can produce serious geopolitical consequences is seen in the fact that they have been the locus of every war since World War II. This instability is expected to continue, as even relatively optimistic projections place the number of people in developing countries whose low incomes deny them the most elementary requirements of decent living at 600 million in the year 2000.[3]

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U.S. relations with the developing world must take into account the extraordinary diversity of a group that includes rapidly industrializing countries like Brazil, Korea, and Yugoslavia; oil exporters like Nigeria, Indonesia, and the Persian Gulf states; poor but technologically advanced states like India and China; rapidly growing exporters of agricultural commodities like Malaysia and the Ivory Coast; and relatively undeveloped, resource-poor countries like those of the Himalayas and the Sahel.

Our relations with these developing countries must also reflect the extraordinary progress that they have in fact made. While technical assistance remains crucial, relations with these countries increasingly require collaboration to meet shared long-range objectives. Such collaboration should in the long run replace the benefactor-to-client relationship, and further reflect the great diversity of LDC political systems, national goals, and overall attitudes to the United States, which range from close friendship to deep hostility.[4] As a final complication, LDCs at all stages of economic development and covering almost the entire political spectrum have found it in their interest to agree on common diplomatic positions and to negotiate collectively in the United Nations and other international forums under the rubric of the so-called "Group of 77."

The United States can thus find itself in conflict with developing countries, individually or collectively, on matters of great political importance. In addition, American interests often call for cooperation with a particular country in one area even when they are in sharp conflict in another. We buy oil from Libya and collaborate on fusion research with the U.S.S.R., to cite two obvious examples. Hence, cooperation with developing countries on shared goals should not be automatically subordinate to fluctuations in bilateral relations, the North-South dialogue, or other foreign relations concerns.

In today's circumstances, the U.S. national interest, and hence the priorities of U.S. foreign policy toward developing countries, needs to be redefined as going beyond concern for the world's poor to include measures to protect America's own economic and material well-being. Science and technology are important factors in both of these priority areas, and should play a more important role in foreign policy toward LDCs.

SCIENCE, TECHNOLOGY AND FOREIGN POLICY TOWARD DEVELOPING COUNTRIES

Science and technology are both critical dimensions of development and the underpinning of America's economic and political strength. As such, they are major components of U.S. policy toward the developing world. Scientific and technological collaboration with LDCs is cheaper than resource transfer, and generally involves less immediate political cost. Science and technology are also key elements of many global issues that can be addressed only by international cooperation in which developing countries must play an important part. Finally, scientific and technological collaboration with these countries is essential to the solution of a number of important problems of scientific research. For all these reasons, such collaboration is critical to the long-term objectives of U.S. foreign policy.

It is also a two-way street. It can no longer be assumed that the problems of development can be solved simply by the "transfer of proven solutions" from the industrialized countries. Such solutions can have serious unanticipated effects if they are imposed without consideration of the economic, social, cultural, and environmental conditions specific to LDCs.

What is more, the United States has much to learn from developing countries in such fields as urban transport planning, where the Singapore experiment in area licensing has greatly decreased traffic congestion and pollution; low-cost public health delivery systems, where the Chinese experience with "barefoot doctors" is a model for the world; and the use of fuel ethanol as a substitute for gasoline, where the Brazilian experiment illustrates both the techno-economic feasibility of the system when there is a surplus of arable land, and the many social problems brought about by major changes in agricultural land use.

Science and technology have already played substantial roles in American policy toward LDCs. But these efforts fall far short of either meeting LDC needs or achieving U.S. goals.

There are often political reasons to engage in scientific and technological collaboration for which the subject of that cooperation is unimportant. Scientific and technological cooperation may in itself be a gesture to symbolize or to help bring about a quick improvement in relations with a particular country. It may be an investment in the long-term development of cooperative spirit and of a cadre of people from the two countries accustomed to working with each other, or as a quid pro quo for a specific but substantively unrelated diplomatic or political concession. This paper, however, stresses those areas in which the substantive results of scientific and technological collaboration serve shared interests, over and above the simple existence of the cooperative effort itself.

These scientific and technological aspects of development and of foreign policy defy easy classification. In this paper we distinguish four inevitably overlapping categories: (1) areas of technological development that are chiefly of humanitarian interest, such as public health, sanitation, subsistence agriculture, and energy sources for the poor; (2) areas of technological development in which the U.S. and LDCs share material long-term interests, such as food and energy; (3) areas of national technological development, based on general U.S. interest in the development of a particular country; and (4) areas in which the United States must balance its interest in LDC development with other conflicting interests. Each of these areas is discussed in turn.

TECHNOLOGIES OF HUMANITARIAN INTEREST

American policy toward the developing countries has been strongly committed to helping meet the basic needs of poor people. We strongly endorse this policy as it applies to scientific and technological development. Scientific and technological research has already had a major impact on the lives of the world's poor. Food production research has helped develop improved varieties of staples like wheat and rice. Research is advancing on "poor man's crops" like sorghum, millet, and cassava. Recent biomedical research promises major advances in the prevention and cure of parasitic diseases which afflict hundreds of millions of poor people. And the development of low-cost techniques for rehydrating victims of cholera and severe diarrheas has already saved many lives in refugee camps and in the poorest LDCs.

Advances in health-related technology occasionally produce a curious combination of relief from human suffering and narrow economic benefit. The eradication of smallpox eliminated an ancient human scourge that had in recent years been almost entirely confined to LDCs. At a much more prosaic level, this historic achievement also saved the developed countries the sizable sums of money needed to vaccinate their own populations and to verify the vaccinations of immigrants and visitors. Smallpox could not have been eliminated without the invention of the technique of concentrating vaccination efforts in high prevalence areas, and the introduction of the bifurcated needle for quick vaccination of large groups of people.

Another example of an area where humanitarian and financial motivations coincide is in the prevention or cure of diarrheal diseases. These diseases are among mankind's major health problems. They kill millions of children in developing countries each year. At the same time, successful programs would be worth billions of dollars to such diverse interests as multinational corporations, national governments, and the international travel industry, all of which send large numbers of people to countries for which they are immunologically ill-prepared. Health research in these areas is thus directly in America's practical self-interest, over and above its critical, but commercially unattractive, humanitarian import.

Despite advances, much remains to be done. For example, it will be financially and institutionally impossible to provide sanitation facilities to urban populations of LDCs by 1990 unless alternatives to water-borne sewerage are used.[5] Better low-cost equipment is also needed to satisfy the energy needs of the poor. For example, simple cookstoves, made of clay and sand and constructed by local artisans for $10-25, have been readily adopted by test groups of housewives in Guatemala and Upper Volta and are reported to reduce the consumption of firewood by 40 percent.[6] Support is needed for both governmental and nongovernmental efforts (such as those of informal "appropriate technology" groups who are frequently in close touch with the poor) to develop and apply such technology at the grass-roots level. Such groups can in some countries help to overcome the social and cultural distance between urban-based scientists and technologists, trained along Western lines, and the poor people in slums and villages.

TECHNOLOGICAL COLLABORATION BASED ON SHARED LONG-TERM OBJECTIVES

In certain areas of technological development, the United States and the developing countries share clearly defined long-term interests. Food and energy are again clearly preeminent, although from a different point of view.

Food

According to the best available estimates, a continuation of present trends through the 1980s will result in major food deficits throughout the developing world which can be met only by greatly increased exports from North America. Such exports, while resulting in gains for American farmers, can be achieved only through much higher production costs and hence higher consumer prices, due to increased investments in fertilizer, water, and other inputs and the lower productivity of marginal land brought into production. Future increases in oil prices and competition for land between food and fuel production and between agriculture and urbanization are likely to raise production costs still further, as will soil erosion caused by the decreasing willingness of farmers to pay the short-term costs of conservation measures.

In other words, American consumers face soaring food prices if the LDCs do not make major gains in agricultural productivity. Moreover, as a practical matter, there is every reason to believe that U.S. agricultural exports will continue to increase (unless the land they require is diverted to the production of fuel ethanol for domestic use). Therefore, it is in the direct interest of the United States to help LDCs mobilize technology to increase their agricultural productivity.

As mentioned above, scientific and technological research has already made major contributions to food crop production technology in developing countries. High-yielding varieties of wheat and rice (together with an institutional structure for training, extension and research that made it possible to take advantage of these varieties, adapt them to local conditions, and convince local farmers to use them) helped to transform India from a significant importer of food grains in the 1960s to a marginal exporter in the mid-1970s. This averted both a major economic and human disaster in India and a substantial drain on the world's food production.

In another area, scientific and technological research enabled tracking of the meteorological patterns that influence breeding, swarming, and migration of the desert locust, and the satellite monitoring of climate features favorable to its increase, greatly reducing the threat of the desert locust in the Middle East and East Africa. By contrast, failure to incorporate genes for rust resistance into the wheat varieties distributed to farmers in another large, poor country led directly to a crop failure and a foreign exchange crisis a few years ago.

Energy

As the United States will for some time to come be a net importer of fossil fuels, it is critically important that a diversity of suppliers be available and that production of fossil fuels for world markets be sufficient to meet demand. Since American reserves are unlikely to increase beyond their current size, and since many of America's allies are inescapably dependent on foreign oil, the discovery of oil anywhere in the world is an important objective of American foreign policy. Energy conservation and the use of renewable forms of energy anywhere in the world are likewise strongly in America's interest—not only because they reduce world demand for fossil fuels but also because they reduce the amount of carbon dioxide that is being added to the atmosphere and is affecting the world's climate.

Credible geological estimates indicate that much of the world's undiscovered oil, natural gas, and other fuel minerals lies beneath LDCs. Therefore, serious exploration and exploitation of conventional energy resources in these countries work to the advantage of the American public. In other words, the United States has a direct interest in seeing that the LDCs have the capability to carry out geological explorations, deal with multinational oil companies, develop energy plans and policies, promote energy conservation, and choose, adapt, and, when necessary, create a renewable energy technology suited to local circumstances.

Moreover, to the extent that developing countries have become self-sufficient in energy through conservation and through development of indigenous supplies—both renewable and nonrenewable—they are less dependent on supplies in a particular part of the world and less prone to political instabilities brought on by balance of payment deficits. To the extent that LDCs avoid "showpiece" development of nuclear power over and above techno-economically justified requirements, they will tend to lessen the incidence of terrorism and weapons-grade plutonium proliferation. Finally, given the inevitability of the spread of nuclear power technology to LDCs, the American public has a vital interest in the ability of developing countries to operate nuclear power plants in ways that avoid both accidents and diversion of nuclear material.

Science and technology are already working to solve LDC energy problems. Brazil's ability to replace much of the gasoline fraction of imported petroleum by fuel ethanol at competitive prices is largely due to indigenous adaptive engineering in locally manufactured equipment for crushing, fermentation, and distillation.

By contrast, another example from Brazil shows how underestimation by the United States of the importance of the place of indigenous technological development can lead to unfortunate consequences. The United States, in accordance with its policy of opposing nuclear proliferation, provoked an international incident by objecting to Brazil's purchase of German nuclear power technology which included reprocessing equipment. Once the political need to stand up to U.S. pressure had passed, the Brazilians realized that they had overestimated their needs for nuclear power, that the contract provisions for technology transfer were not as favorable as they had first thought, and that the program was likely to tie up a disproportionate share of their engineering manpower. Brazilian energy policy is apparently being readjusted accordingly.

In addition to food and energy, there are a number of other areas where scientific and technological cooperation with LDCs meets definable, if less concrete, U.S. interests. These range from financial interests to scientific and environmental concerns to broad-based political issues.

Ecological and Cultural Heritage

Much of the world's irreplaceable ecological and cultural heritage lies in the LDCs. This heritage includes such diverse treasures as ancient monuments and works of art, ancient cities (some of which still teem with people), game parks, the habitats of such endangered species as the Bengal Tiger, and vast stretches of undisturbed tropical rain forest. These forests contain countless endangered species of inestimable economic potential that constitute a genetic treasure incalculably greater than that of the celebrated snail darter. Anthropologists and ethnobotanists working in these areas indicate that many more useful substances are likely to be found in the primitive medical lore that has given the world quinine, reserpine, and digitalis. The report of the U.S. National Academy of Sciences, entitled *Priorities for Research in Tropical Biology* (Washington, D.C., 1980), lays out a crash program to salvage as much scientific value as possible from the few years available in which to study these vanishing ecosystems.

Absence of adequate technology has been an important factor in the adoption of ecologically harmful development practices in many of these areas. To conserve these treasures requires research in such natural sciences as ecology and wildlife biology and the study of the preservation of materials. It also requires institutional innovations that further national and global aims by addressing local needs. For example, the careful planning of tourist facilities to enable local tribesmen to share in tourist revenues shows promise of permitting East African governments to conserve their great game parks both as assets to national development and as part of the world's ecological heritage.

In a historical and philosophical sense, perhaps, these treasures are the common heritage of all humanity. As a practical and political matter, this heritage will be lost unless its preservation is in the interest of the (usually hard-pressed) LDCs whose sovereignty prevails. If Americans wish these treasures to survive, it is in their interest to help developing countries to mobilize the technology needed for their preservation.

Rapid Population Growth and Unemployment

These issues are distinct in origin but together give rise to one of the most serious problems confronting the developing countries—one that also affects the United States both directly and indirectly. The urban unemployed and underemployed are among the chief sources of political instability in LDCs, many of which occupy geopolitical positions of strategic importance. The lack of employment opportunity in both rural and urban areas of these countries is the main pressure for illegal migration to the United States. Forced by rapid population growth and regressive systems of land tenure to extend their struggle for survival to marginally productive forests and deserts, the world's poor are exerting devasting environmental pressures in such areas.[7] These root problems cannot be bottled up indefinitely.

The population problem is ideally suited to the scientific and technological cooperation of both the public and private sector and both the natural and social sciences. The development in the 1960s of such modern contraceptive methods as the pill, intrauterine device, and injectable contraceptive, made the establishment of family planning programs possible in LDCs. Such programs require a sensitive understanding of specific LDC needs; of the risks of using industrialized nations' approaches, standards, and systems in inappropriate settings; and emphasis on the building of local capability. Major technological needs appear to be in biomedical research related to human reproduction, and in efforts to develop and commercialize promising contraceptive technologies that have passed the research stage.

The unemployment problems of developing countries are based to some degree on inappropriate patterns of technological development. These are caused, in turn, by lack of local technological capacity, lack of information regarding technological alternatives, uncritical copying of the technologies observed in developed countries, and government policies that overly protect against internal and external competition, encourage excessively capital-intensive investments, and discriminate against small-scale industry.

In most developing countries, there is a crucial need for development strategies that create productive jobs. These require policies designed to encourage investment, and if necessary develop, technological alternatives that are both efficient and suited to labor-intensive operation. Such measures should be combined with policies to increase the demand for technology, to create and strengthen scientific and technological infrastructure and human resources, to build technological capacity in the productive sector, and to remove incentives that bias technological development toward inappropriately capital-intensive solutions.

While these are primarily matters of domestic policy, there is ample room for international collaboration on the development of labor-intensive technologies. Research has shown that earth for civil works can be moved by large numbers of workers as efficiently as by machines, if proper attention is paid to the training of foremen, the nutrition of workers, and the quality of hand tools. Similarly, agricultural engineers at the International Rice Research Institute in the Philippines have designed a variety of low-cost machinery for the production of paddy rice and have assisted local firms to manufacture them.

Such research cannot by itself solve the LDC unemployment problem. But it can demonstrate that improved labor-intensive technology is feasible and can serve as the basis for industrial strategies that give equal weight to growth and the creation of productive jobs.

Geophysical Research

Research on the frontiers of oceanography and meteorology, which is critical to the development of long-range weather forecasts and to the location of undersea mineral resources, requires the full cooperation of developing countries. A major frontier of numerical climatology, the discipline that deals with the global circulation of the earth's atmosphere, lies in the understanding of the tropical atmosphere and its interaction with the oceans and with temperate regions. Research in this area is needed, both for long-range weather forecasts in temperate regions and for an understanding of the monsoons on which most tropical agriculture depends.

Many areas of critical interest to oceanographers lie well within the 200-mile limit of coastal jurisdiction of developing countries. These countries require assurance that the research vessels are not a cover for commercial or military espionage. More fundamentally, they should enjoy full participation in the gathering and interpretation of the data. Either goal would require a considerable strengthening of the technological capacity of coastal LDCs, a strengthening that is in the best interests of the oceanographic research community and hence of American foreign policy.

Threats to the Global Environment

Several critical global environmental problems are beyond the ability of any one country to address individually and require a cooperative effort by all nations. Scientists now agree, for example, that burning fossil fuels and clearing forests will increase the carbon dioxide content of the atmosphere to the point where it will change the world's climate in a significant though unpredictable way over the next 50 years or so.[8] Moreover, through a complicated chemical sequence, the use of fertilizer may reduce the strength of the atmospheric layer of ozone that protects the earth from ultraviolet radiation.

Developing countries are major contributors to the loss of carbon in soil and standing biomass through deforestation, and several of the more advanced LDCs are or soon will be major users of fossil fuels and fertilizers. Both of these issues are rife with scientific uncertainty and require monitoring and research on a global scale.

The United States has a direct interest in the participation of developing countries in global research efforts on these issues. In order to participate in such international efforts, LDCs must have the scientific and technological capacity to recognize that the world faces a serious problem, that their participation is important, and that they need to participate in appropriate international research, monitoring, and remedial measures. Although LDCs will be justifiably convinced that their primary need is for meteorologists and climatologists who can apply their skills to agriculture, transport, and other more immediate problems, it should be possible to harmonize national and international areas of need.

Scientific and Technical Collaboration and Foreign Policy Goals

This broad survey of the scientific and technological aspects of American foreign policy toward the developing countries has identified numerous areas where long-range cooperation could contribute to concretely defined foreign policy objectives and to important developmental goals. (Technological "stunts" designed for short-term impact on bilateral relations have been deliberately excluded.) Among the long-range goals:

- Diversifying sources of oil for America and its allies;
- Freeing developing countries from economic and political dependence on a small number of oil exporting countries by encouraging energy conservation and the discovery and exploitation of renewable and nonrenewable energy resources;
- Decreasing the long-run increase in world food prices by encouraging food production;
- Alleviating problems of rapid population growth, unemployment, and migration;
- Conserving the world's cultural and ecological heritage;
- Improving technology for exploiting undersea resources and for predicting long-term weather conditions;
- Managing global environmental problems;
- Improving health care technology and its availability.

Choices among these options depend on both objectives and preferred approach. How can one choose rationally between starving people, sick children, vanishing ecosystems, and stable governments?

Of the global problems in which the U.S. stake is clearest, food and energy are of urgent importance and lend themselves to concerted international action. The accomplishments of the Consultative Group on International Agricultural Research (CGIAR) show the power of this approach in addressing the problems of both rich and poor. It is essential that U.S. support to CGIAR be expanded, and that a global program for mobilizing energy technology be quickly developed and funded so that LDCs can take advantage of all appropriate sources of energy, both renewable and nonrenewable. (For further discussion of CGIAR, see the paper by Sylvan Wittwer in this volume.)

Another urgent international need is for action to study and conserve ecological and cultural treasures that will otherwise be lost forever. Programs in this area should begin immediately, but full mobilization will take some years to build up because of the scarcity of qualified personnel.

Population research is no less urgent and important than research on food and energy. A substantial international effort is already under way so that priorities for new international action are less clear. Given the certainty of limited political and financial resources in the early 1980s, major initiatives on population research may have to be deferred until some degree of consensus can be reached. The achievement of such consensus is thus an important policy objective. (Additional discussion of this topic will be found in the paper by Michael Teitelbaum in this volume.)

SCIENCE AND TECHNOLOGY AS A DIMENSION OF NATIONAL DEVELOPMENT

A succession of U.S. administrations has viewed the overall development of LDCs as in the long-run interests of the United States. In addition, the United States has from time to time taken a specific interest in the development of particular countries deemed of special geopolitical interest.

In either case, sound long-term development requires attention to a broad range of scientific and technological considerations. In particular, local technological capacity is a prerequisite to an effective attack at the national level on virtually any of the global problems noted in this discussion. For example, lack of indigenous technological capacity often leads LDCs to adopt sophisticated technologies used in developed countries, which frequently wastes scarce capital and foreign exchange, contributes to widespread unemployment and severe disruption of social traditions, and leads to economic and political crises. Lack of technological capacity also hinders efforts to develop local energy sources. High rates of population growth, coupled with development policies that fail to encourage the use of employment-creating technology, fuel political unrest and the unwanted migration of workers.

The fields of science and technology are thus not the arcane preserve of specialists in universities and research laboratories but are basic to development strategy. To the extent that U.S. foreign policy is concerned with the long-term health of specific developing countries or of the developing world in general, there must be a clear understanding of the scientific and technological dimension of development. This dimension includes not only research and development, but the application of innovative technologies and the choice of technologies from "off the shelf." It also encompasses the formation of human resources, the development of local capacities to adapt, absorb, create, and use technology, and the elaboration of national and sectoral policies designed to encourage technological innovation, to assess its effectiveness, and to guide it into socially useful directions.

The scientific and technological dimension of development further includes the capacity to adjust to advances in technology and to the technological consequences of such global trends as changes in the price of energy and other key commodities. Included as well is the capacity for informed participation in research and policy discussions on global technological and environmental issues.

As is clear from the discussion thus far, our definition of technology is deliberately broad—namely, the application of knowledge to achieve a practical objective. Thus defined, technology includes both equipment (hardware) and the institutions and management practices (software) needed for its effectiveness.

By this definition, technological development includes the evolution of the technology in use in a country as well as the country's development of its capacity to mobilize technology—i.e., to assess needs, resources, and challenges, and to choose, adapt, create, and implement technology to meet defined objectives.[9] Such capacities can be found in universities, technological institutes, research laboratories, government agencies, private or publicly-owned consulting firms and producer enterprises, or small volunteer organizations. They require skills derived from both the natural and social sciences, and these skills are needed in some form at all stages of development.

In the early stages of technological development, a country must concern itself with the building of basic scientific and technological infrastructure—a university, minimal research facilities and a technical library, followed by scientific professional organizations and some form of national research council to administer fellowships, to coordinate research funding, and to relate research to the country's needs. An agricultural research laboratory and the rudiments of industrial standards then follow.

Moravcsik and Ziman, in their classic article, "Paradisia and Dominatia," have described the difficulties facing the scientist from a developing country who, with his Ph.D. fresh from a leading American or European university, returns home to discover that he must now assume responsibility for building a curriculum, a library, a workshop, a department, and sometimes a national scientific community—all tasks for which he is completely unprepared—as well as carry on research with inadequate funding and with few of the support services that young American scientists take for granted.[10]

The most difficult problem of technological development—that of relating the fledgling scientific and technological community to the mainstream of the economy—arises in its most elementary form at these early stages. Every developing country faces major decisions which cannot be deferred until it achieves a reasonable measure of technological capacity. Investment projects must be planned and development policies devised. The infrastructure inherited from the colonial past must be maintained and expanded to meet the demands of modernization. The past and probable future effects of the introduction of technology must be assessed and the range of technology in use must be broadened.

Except for a few oil exporters, LDC resources such as money, managers, trained people, and institutional and physical infrastructure are limited. Political leaders and economic planners are beset with pressing social, economic, and political problems. Their staffs typically include able, highly trained professionals who are equal to the best in any country. But they are usually few in number and are thinly stretched over an enormous range of responsibilities. Moreover, they are rarely familiar with science and technology and neither provide substantial resources for research nor press for sorely needed technological development. There is also a large, unmet, and urgent need for informed indigenous control of decisions concerning the overall conception and design of policies and projects, to insure that technological development choices are made with the full involvement, understanding, and concurrence of local people, and with local conditions and needs fully in mind.

The problems of undeveloped technological capacity are acute in developing countries which have come into sudden wealth through the export of petroleum. These countries must somehow invest vast sums quickly, under intense political, social, and commercial pressure while simultaneously developing local capacity, often virtually from scratch.

Thus defined, technological development lies at the heart of political stability and development strategy. To the extent that U.S. foreign policy is concerned with long-run development in LDCs, it should seek to foster a strong indigenous technological capacity where it is lacking. The development of local capacity should be an essential element of efforts to attack the more immediate and specific scientific and technological problems covered in the discussion that follows.

Many developing countries, on the other hand, have achieved a substantial degree of technological capacity. In these more advanced countries, the basic technological infrastructure is typically in place, but in most, patterns of development have been based on the importation of foreign technology with little effort to learn to adapt it to the local situation, to reproduce it under similar conditions, or to improve it. These patterns have left technological institutions isolated from the economy. In these countries, moreover, economic policies that affect interest rates, exchange rates, and wage and tariff levels, have frequently been responsible for a pattern of technological development that is inappropriate to local factor prices and that fails to create enough productive jobs.

Despite their relatively advanced level of technological capacity, these countries hold some of the poorest people in the world. Too often social programs designed to improve their lives or develop the informal sector neglect to encourage scientific and technological research and innovation, resulting in little demand for the development of the simple, low-cost technology that could address their most pressing problems.

In the most advanced developing countries, scientific and technological research, development, and innovation are important elements of market competitiveness. In some of their exports, these countries use up-to-date means of production, adapted to local conditions. They also use modern techniques to identify and service their markets. Some have also begun to export technology, usually to other developing countries, in the form of capital goods, turnkey plants, licenses, and technical services.

CONFLICT AND COOPERATION IN TECHNOLOGICAL DEVELOPMENT

U.S. foreign policy toward technological development in LDCs, especially those that are more advanced, is ambivalent. However much it may appreciate the role of technological capacity in long-term development strategy, the United States must consider a variety of issues in which its interests may conflict with those of specific LDCs. Such issues include commercial competition, the "export of jobs" through overseas investment or technology transfer, the threat or reality of nuclear proliferation, the supply and price of raw materials, and the possible conflict between the desire of an LDC to develop its own industry and technology and that of the United States to export its manufactures, agricultural products, and services.

These considerations are present to some extent in U.S. relations with technologically less advanced countries, particularly oil exporters, that are major powers in global resource politics, important markets for equipment and services, and potential competitors in capital- and energy-intensive products like fertilizers and petrochemicals. Indeed, conflicts over such issues as controls on the import of toxic substances are most acute in countries that lack the technological capacity to draw up and operate an appropriate regulating mechanism.

As an additional complication, many of these issues have entered the North-South dialogue in the form of demands for improved access to proprietary technology, international codes of conduct for technology transfer, buffer stocks to stabilize the price of commodities exported by LDCs, and international arrangements for the exploitation of undersea minerals. These issues are pressed most vigorously in international diplomatic forums by governments of more advanced LDCs who seek to advance the interests of their growing modern industrial sector.

For the U.S. policymaker, these areas of conflict are awkward in three ways. First, they are sufficiently specialized that they rarely attract the sustained interest of high-level officials. Second, many concern areas of commercial interest in which the government is reluctant to become directly involved. Third, many of the remedies proposed by the LDC representatives may not, in fact, be the most technically effective ways to address the problem.

Although the U.S. response to these demands clearly involves more diplomacy than technology, the most constructive response would be to identify and study that portion of the problem where North and South have interests in common, to define its practical content carefully, and to devise and promote a mutually beneficial technical solution. Whenever possible, this type of solution could be pursued, designed, and implemented independently of the broader controversy. The purpose is not to win the diplomatic confrontation but to make progress toward solving the long-range problem. This approach seems more attractive than the alternatives, which are (with some oversimplification) either to "stonewall," or to offer a less expensive solution which is demanded by the developing countries and which the United States has good reason to believe would not be effective. The following pages briefly outline several tentative applications of this approach to some of the thorny problems confronting U.S. diplomats in areas of science, technology, and development.

Transfer of Commercial Technology

This issue has come to symbolize to the business community all the technological aspects of foreign policy toward the developing world. Developing countries have, through a variety of diplomatic forums, pressed for an easing of the costs and conditions of the transfer of commercial technology through a binding international code of conduct. Some have even asserted that knowledge should be a free good. Developed countries have replied that they did not have, nor wish to assume, control over such commercial transactions in the private sector, that commercially useful knowledge was costly to produce and deserved its full market value, that most of the technology needed by developing countries was available without restriction and even without charge, and that any abuses could best be (and indeed were being) dealt with through national government regulations.

These disagreements are in one sense an extension of international business negotiations between suppliers and purchasers of technology. Many LDCs, in exercising their sovereign right to do so, have established regulations on the international commercial transfer of technology, which typically limit the size of royalties and prohibit certain provisions in commercial agreements. Agreements are often not allowed to ban the export of products made with imported technology or to require that raw material be purchased from the technology supplier. A regulatory body may be required to participate in the negotiations between suppliers and purchasers of technology.

At the pragmatic level, proponents of such regulations assert that they limit the foreign-exchange costs of technology transfers and eliminate onerous restrictions without hindering the flow of technology. Critics assert that supposed savings may simply be shifted to some other entry in the foreign-exchange outflow ledger or may be counterbalanced by the loss of benefits caused by project delays while the transfer agreement is being reviewed and approved. Only time will tell whether such regulation will in fact improve the terms of technology transfer without slowing it down.

In the meantime, there may well be unexplored avenues for collaboration in areas of mutual benefit. U.S. business has an interest in promoting the sale of technology, whether in the form of equipment, technical services, licenses, or know-how. U.S. labor shares this interest, as long as these sales are matched by investments in domestic innovation intended to ensure continued U.S. competitiveness and with assistance to workers displaced from noncompetitive industries. Assuming that domestic innovation does not slacken, there is every reason to explore the possibility of creative mechanisms to encourage technological collaboration between U.S. and LDC firms.

Such measures already form part of U.S. bilateral agreements with Israel. A bilaterally funded foundation in that nation promotes technological collaboration between private firms in the two countries, typically but not exclusively providing for research and development leading to the commercial application of an Israeli technology using U.S. marketing skills. Over the next several years, the same pattern could be extended to other relatively advanced countries such as Korea, the Philippines, Taiwan, Thailand, Brazil, Mexico, and Jordan. Comparable programs of cooperation might be arranged among trade or professional organizations. Another interesting suggestion is that of Jack Baranson, who has pointed out the need for a special facility to finance the front-end costs of a technology supplier in the United States who must incur expenses for technical services months or years before he receives royalties based on sales.[11]

Negotiations with Transnational Corporations

The wide areas of disagreement between developed and developing countries with respect to the activities of transnational corporations should not obscure their agreement on one fundamental issue: stable business agreements are in the interest of both sides, and the most stable agreements are those that are equitable. This premise leads directly to the somewhat paradoxical conclusion that it is in the direct interest of transnational corporations that their overseas counterparts be skilled in negotiations so that they may arrive at agreements which protect their interests and which they expect to fulfill. This interest extends to the United States government, not only because of its interest in U.S. commercial relations abroad, but because disputes with overseas investors constitute a major irritant in bilateral relationships with developing countries.[12]

Scientific and Technological Information

Developing countries have demanded improved access to scientific and technological information, which they find to be a near-monopoly of the industrialized countries. This demand sometimes takes the extreme form of unfettered access to proprietary information. More recently, it has been embodied in a proposal for a cumbersome network of national focal points (too often serving as information depositories rather than information services) under United Nations auspices, which in this author's view will do little to aid the supposed beneficiary of the system, namely the user of technological information in the developing country.

The United States has an obvious interest in helping developing countries meet their technological information needs, especially when the technology is produced in the U.S. To date, the major U.S. response to such demands has been a modest but useful program to improve access to the huge store of technical information in the National Technical Information Service (NTIS). Further efforts in this area would require the development of information networks at the national level designed to help the LDC user define and meet his own needs for information. Such systems could then develop means of access to the many existing data banks around the world. It would then be in the U.S. commercial interest to facilitate the access of such national services to any U.S. sources not covered by existing systems, and to maintain a professional staff to handle specialized information.

Commodities

Developing countries are convinced that they are being victimized by low and fluctuating prices for natural commodities that they export. Although the United States has generally resisted strong diplomatic pressure for buffer stocks and other devices to alleviate this problem, it has supported research and development on many such commodities, which is much less expensive than buffer stocks, and which is in the long-term interest of both producers and consumers.

Careful attention to agricultural and technological research has allowed natural rubber to compete effectively with synthetic rubber, providing consumers with a useful engineering material and allowing Malaysia and other rubber producers time and foreign exchange needed to diversify into other crops. This experience, and that of international organizations concerned with wool and cotton, has shown how research, integrated with marketing and promotion in a commercially oriented strategy, can defend the market competitiveness of a natural commodity against intense competition from synthetic substitutes. By contrast, neglect of modern marketing techniques and inadequate agricultural and industrial research have been primary factors in the rapid decline of the market for jute, a principal export of Bangladesh and India.

The United States is a charter member and major supporter of the International Institute for Cotton (IIC), an intergovernmental organization for the defense of the market competitiveness of cotton through industrial research, promotion, and service to the textile trade. The United States has also supported the proposal for a Cotton Development International (CDI), which would absorb the Institute's program and extend it into agricultural research and into a more active role in increasing the amount of cotton used by the LDC textile industry.

The CDI proposal, made public in 1976, is still under discussion by governments. Unfortunately, it has been considered a subsidiary issue in discussions underway at the United Nations Council on Trade and Development (UNCTAD) for cotton buffer stocks—which many negotiators feel is the "real" issue, regardless of the fact that the technological defense of market competitiveness can achieve major results at much lower cost. Consequent delays have threatened the future, not only of CDI, but of IIC itself.

The history of the CDI proposal illustrates the difficulties faced by constructive attempts to develop practical, mutually beneficial programs of scientific and technological cooperation in this highly politicized area. Nevertheless, such efforts deserve U.S. support, especially when they concern commodities, such as cotton and jute, which contribute heavily to the livelihoods of poor people in LDCs.

Communications

LDCs exert major diplomatic leverage in two international organizations that have a substantial influence over global communications policies of importance to the United States. First, the United Nations Educational, Scientific, and Cultural Organization (UNESCO) is engaged in a major debate over measures to rectify the imbalance in information flows between developed and developing countries, which are convinced that journalistic coverage by private news services is in some cases insensitive and displays insufficient understanding of their problems.

The United States fears that the measures proposed by LDCs to UNESCO could legitimize the efforts of governments to control the flow of news from their countries. Second, the International Telecommunication Union is responsible for convening intergovernmental conferences to allocate radio frequencies among conflicting uses—a function of both military and civilian significance. U.S. diplomacy in both cases suffers from the absence of any program to assist developing countries with their communications problems. Yet, this is an area where the most advanced U.S. technology has clear application to important development problems that would be difficult to address in any other way.

Substances Involving Hazard

U.S. environmental groups have occasionally proposed that the export of such substances be subject to the same restrictions as their domestic use. The balance between risks and benefits in developing countries differs greatly from that in the United States, however. The United States would assume an impossible burden if its courts had to decide, for example, whether DDT should be used to control malaria in Sri Lanka or whether insecticides are being properly applied to cotton crops around the world.

On the other hand, many developing country governments cannot deal effectively with the pressures, both internal and external, to allow misuse of these useful but dangerous substances. Toxic substance exporters often help LDCs draft codes of control, but may do so in a self-serving manner. There have been instances of efforts to influence foreign governments to use pesticides improperly or excessively, and of warning labels which are unreadable by foreign users or which lack essential cautions. While there is no perfect solution to this problem, it would be to everyone's advantage to help LDCs to build up their own capacity to deal with these matters and protect their own interests.

An analogous situation exists in the field of pharmaceuticals, where there is an obligation—not always perfectly honored in practice—to warn physicians and consumers of possible side effects and contraindications. Here, too, risk-benefit factors may be different in an LDC than in the United States. A country in the midst of an epidemic may be willing to license a vaccine or drug with significant side effects, even though there would be no need to accept these risks in the United States where the disease is virtually nonexistent.

This issue has become particularly acute in the case of the injectable contraceptive Depo Provera. Depo Provera has not been approved for contraceptive use in the United States because of studies that suggest a possible link with cancer, and other side effects. Numerous LDCs nevertheless use this substance and request that the United States provide it, arguing that their population problems are urgent and that the risks of pregnancy and childbearing in their countries far outweigh the drug's possible hazards.

It is a mistake to impose U.S. conditions on LDCs and to argue, as some U.S. groups have done, that drugs such as Depo Provera should not be exported because they carry risks unacceptable in this country. In the end, it is the LDCs themselves, through development of their own regulatory capacities, who will decide the appropriateness of any imported technology.

CURRENT U.S. POLICY AND PROGRAMS

We have not attempted a comprehensive review of U.S. programs for scientific and technological cooperation with developing countries, or of the policies that underlie them. What follows is a brief overview of existing policy and practice, with particular emphasis on bilateral programs, for the purpose of comparison with the approaches recommended in this paper.

For convenience, we distinguish four broad, and in some cases overlapping, mechanisms for U.S. bilateral scientific and technological cooperation with LDCs:

(1) Bilateral agreements with countries of geopolitical importance;
(2) Development assistance programs;
(3) Extension of domestic programs into the international sphere;
(4) Programs set up in pursuit of global policy objectives.

BILATERAL AGREEMENTS

The United States has signed agreements of bilateral cooperation in science and technology with (then) developing countries as diverse as New Zealand, China, Egypt, Saudi Arabia, and Spain. Many of these agreements have resulted in large and important programs.

From the point of view of U.S. foreign policy toward the developing countries, the chief function of such agreements has historically been to improve the atmosphere of bilateral relationships. Such efforts have followed a prescribed order: first, the exchange of athletic and cultural attractions; then the scientific mission to arrange a cooperative agreement; then, the addressing of "real" issues. The objective of the scientific mission was to create some cooperative effort between the United States and the other country; the subject of cooperation was unimportant and could be left to the scientists, who typically chose subjects where research capacity in the cooperating country was strong, regardless of its relevance to national needs. Conversely, if bilateral relationships were chilly and a thaw was considered undesirable, there has been little or no provision for scientific and technological cooperation.

Recent bilateral agreements with China and several African countries show an encouraging shift from this pattern, at least in the choice of the subject for cooperation. Formal agreements were preceded by surveys of each country's needs to identify the best subjects for bilateral cooperation. These agreements ranged well beyond research to include, for example, collaboration in water resources planning in major Chinese river basins.

Another interesting bilateral experiment is the U.S.-Israel Binational Foundation for Industrial Research and Development, mentioned earlier, which encourages commercially motivated enterprise-to-enterprise technological cooperation in the private sector. The work of this foundation provides, to this author's knowledge, the only example in the U.S. federal government of direct support to industrial research and development awarded on purely commercial criteria.

DEVELOPMENT ASSISTANCE

Science and technology have formed part of American bilateral development assistance for many years. Assistance programs have supported, for example, research on human reproduction, forestry, water resources, pest control, and tropical diseases. These assistance funds have also supported a useful series of publications by the National Academy of Sciences that conveys, in compact form, the state of knowledge in relatively unexplored fields of science and technology which promise applications of high economic potential in LDCs. Examples include ferrocement, unexploited species of tropical legumes, and fast-growing trees.

Since 1973, the objective of the foreign aid program has been to help meet the needs of the desperately poor for food, health, education, and in recent years, fuelwood. This humanitarian objective has been a prerequisite to continued congressional support for the development assistance budget and has inspired efforts critically important in the global struggle to alleviate poverty.

Assistance programs under this new policy support the development of research capacity in these fields in the poorest LDCs, which are now the sole recipients of development assistance. In addition, a major new group of programs, called the Collaborative Research Support Programs, supports the building of U.S. capacity to collaborate with food and nutrition researchers in LDCs.

The shift in emphasis to the problems of the poor has also increased interest in low-cost technology. Since much of the technology used to solve comparable problems in industrialized countries is far too expensive for poor LDCs, development assistance agencies have been forced to consider innovative solutions to problems such as health services, nutrition, and basic education, in order to meet these needs at a cost low enough that the approach can be extended to large numbers of people within the resources available to the developing country.

Several U.S. Congressmen have indicated a further special interest in "capital saving" technology as the key to meeting the needs of the poor, and have added provisions to foreign aid legislation to ensure the use of such technology. This has prompted support to community action groups in LDCs capable of applying such technology to the needs of the poor through the U.S. Agency for International Development (AID), the Inter-American Foundation, and Appropriate Technology International.

These efforts have been useful correctives to the tendency of development assistance agencies to apply familiar technologies even when these are unsuited to the problem at hand, and have given new legitimacy to technologies that might otherwise have been regarded as unworthy of a modern country. On the other hand, they run the danger that "appropriate technology" may be rejected as second-rate or dismissed as the latest fad or panacea without proper consideration on its merits.

The United States has made major contributions to multilateral agricultural research on food crop production, and to biomedical research in tropical diseases and human reproduction. It has also given substantial support to building the needed capacity for carrying out research on these problems. The food crop research financed by CGIAR has been an outstanding success. As a funding mechanism, the group is already serving as a model for the financing of research in fields which lend themselves to integrated global programs under international management and control. Such research has sometimes taken place in international centers, but in other cases has taken the form of a network of research institutions in developed and developing countries, such as that of the Integrated Program of Training and Research on Tropical Diseases of the World Health Organization.

INTERNATIONAL EXTENSION OF NATIONAL PROGRAMS

Many programs developed for scientific and technological research in the United States have been extended to other countries. The National Aeronautics and Space Administration (NASA) has supported experimental applications of satellite techniques of remote sensing in developing countries; the Communicable Disease Center and the U.S. Department of Agriculture have, respectively, investigated diseases and insects that posed threats to the United States; and the U.S. Geological Survey has studied earthquakes and volcanic eruptions in foreign countries to provide insight into similar events in the United States.

All of these programs provide technical assistance to their LDC counterparts, although more as a by-product than as a primary objective. Increased attention to this technical assistance could, at relatively low cost, greatly increase the effectiveness of these programs in building LDC problem-solving capacity, and contribute to the global stock of knowledge on these subjects of worldwide interest.

PROGRAMS IN SUPPORT OF GLOBAL OBJECTIVES

By far, the major thrust of U.S. pursuit of global policy objectives has been in programs to abolish poverty. But there are also several U.S.-supported programs that deal with issues of global significance not directly connected with poverty.

U.S. participation in the Global Atmospheric Research Program of the World Meteorological Organization is primarily intended to provide the scientific basis for long-range predictions of U.S. weather. This objective can only be fulfilled through international cooperation, as it requires a global effort to fill major gaps in meteorological (and to a lesser extent oceanographic) data. Many of the most important of these are in the tropics. For this reason, U.S. participation in this program, although not primarily intended to assist developing countries, provides tens of millions of dollars for the study of the tropical atmosphere, a subject of critical interest to these countries.

Examples of efforts intended to fulfill global objectives are the international programs of the Department of Energy. The Department has published long-range assessments of the energy needs of Peru, Egypt, and several other countries. While the prime objective of this program is to slow the spread of nuclear power, its executors quickly realized that they had no choice but to try to take the point of view of their "customers" and to provide them with full assessments of all their energy options, including nuclear power. Such an approach, it is hoped, will discourage nuclear projects that are motivated by prestige and that lack techno-economic justification. On the other hand, these studies have not attempted to build local capacity for needs assessment and have sometimes tended to project U.S. conditions and requirements onto the developing countries without fully evaluating the alternatives.

GENERAL ASSESSMENT

It has long been apparent that U.S. programs of scientific and technological collaboration suffer from fragmentation, omissions, and lack of funding or institutional support within the government. As Eugene Skolnikoff has pointed out in his "synthesis" paper in this collection, it has proven very difficult to fund programs which can neither compete at par with the best of American science, nor be justified as aid to rural development in the poorest LDCs. These are important priorities, but surely do not span the whole set of objectives of American foreign policy or of the overseas aspects of American technology policy.

As early as 1971, the National Academy of Sciences recommended the establishment of an International Development Institute, separate from AID, as a focus for scientific and technological cooperation with LDCs as distinct from the transfer of resources. This proposal was revised and brought up to date after a thorough study by the Brookings Institution of the bureaucratic difficulties faced by AID in its attempts to support scientific and technological programs.[13]

In 1978, building on the Brookings study, the White House Office of Science and Technology Policy proposed an Institute for Scientific and Technological Cooperation (ISTC) as a mechanism to encourage and coordinate scientific and technological cooperation with LDCs. Establishment of ISTC was to fill several gaps in the institutional framework for dealing with technological problems in LDCs: to increase support to research and development, free of the pressure of the immediate priorities of AID programs and of the state of bilateral relations with cooperating countries; to enable research support for projects not directly related to "basic human needs"; and to develop programs of scientific and technological cooperation with middle-income countries such as Brazil, Mexico, and Korea, which are "graduates" of aid programs and on the way to becoming major industrial powers.

The ISTC proposal reflected increased understanding of the complex role of science and technology in development—as an important dimension of development rather than a "fix," a panacea, or a stunt. It recognized that technology covered a broad range of levels of sophistication, from satellite-based remote sensing to improved clay-and-sand cookstoves. It recommended that sociological and institutional constraints to the diffusion of improved technology be explicitly addressed, and that particularly complex problems—such as nutrition and public health—be addressed by integrated research on technology policy and institutional design. Finally, it gave developing countries a role in the management of the Institute through the establishment of an advisory council on which they were to be represented. All these were important advances.

Congress has not approved the establishment and funding of such an independent ISTC, allowing instead only a small increase in the budget for science and technology within the regular AID structure. AID has established the position of Scientific Advisor in the Office of the Administrator, and is making arrangements to fund research on topics identified by the National Academy of Sciences through its Board on International Science and Technology for Development.

This is not the place to assess the prospects of some version of ISTC for eventual enactment, or to critique the efforts of its planners who worked under difficult pressures of time and politics to design it and to justify it to the Congress. Some of the participants in that effort have suggested in personal conversations with the author that the difficulties were no more fundamental than the failure to convince skeptical members of Congress that the laudable objectives of ISTC, to which the Congress was basically receptive, could not be achieved within existing organizations. A few are even convinced that scientific and technological cooperation will become the major thrust of U.S. bilateral development assistance over the next several years, partly because science and technology is the area in which the United States has the most to offer, and partly because this kind of cooperation is cheaper than financing large investment projects.

Others, by contrast, cite the uneasiness of politicians at the premise that science and technology can fully contribute to LDC needs only if scientists are given a greater voice in such efforts and are able to use resources without the constraints of existing organizations.

In any case, the refusal of the Congress to appropriate funds for the ISTC or to contribute to the U.N. Interim Fund,[14] combined with the increasing unpopularity of foreign assistance—as shown by the annual difficulties faced by the foreign aid bill in Congress—show clearly the present lack of a strong domestic political constituency for improved scientific and technological cooperation with the developing world. The author would suggest that it is time to seek to create or strengthen the domestic political constituencies for such activities.

A likely basic constituency would seem to be the U.S. scientific and technological community. However, with the exception of a relatively small number of professionals concerned with scientific and technological development in LDCs, there is an absence of strong interest in this field among much of the leadership of the U.S. scientific and technological community. Proposals for support of research on problems of interest to LDCs, whatever their intrinsic scientific interest or practical importance, have been regarded as competition for budget resources with the "real" interests of the American scientific community—namely, those problems defined by purely domestic interests of the United States.

There has been some change in this attitude, partly because of the expansion of scientific and technological cooperation with China, the Middle East, and (to a lesser extent) Africa. Technical journals such as *Science, The New Scientist,* and the *Bulletin of the Atomic Scientists* have begun to devote increased space to issues concerning developing countries. But there has been far too little effort to convey both the human importance and the intellectual challenge and excitement of the scientific and technological problems confronting the developing world.

American scientists should, in the name of devotion to the pursuit of knowledge, assume some responsibility for the professional survival of their colleagues in LDCs. They should encourage American funding agencies to make available the relatively small sums needed to keep scientific research alive in these countries, and should acquire the knowledge needed to be able to prepare students from these countries for the special problems they will face on their return home.[15]

Popular interest among Americans in the scientific and technological problems of LDCs has been limited to subjects that echo the domestic concerns of organized groups. Public interest groups have rendered a useful service in spotlighting the particular technological problems faced by women in developing countries, as well as the need to protect endangered species from commerical exploitation.

Occasionally, however, the projection of domestic political issues onto the different conditions of LDCs results in a somewhat distorted perspective. We have already discussed the difficulties of applying arguments designed for U.S. conditions to the problems of pesticide and contraceptive use in LDCs. There are many similar policy issues. The use of infant formula is heavily promoted to the poor in LDCs who cannot afford and frequently misuse it. Yet, such products are as essential to working mothers there as they are here. Here public pressure to discourage irresponsible advertising can have a useful effect.

Wages, working conditions, and safety and environmental safeguards in most developing countries are far below U.S. standards. In many cases, scandalous conditions could be improved at little cost. Yet, LDCs cannot afford the unquestioning application of the standards typical of advanced countries. Here the efforts of U.S.-based labor unions to raise the awareness of their colleagues in LDCs are far more effective than calls for protection against "cheap labor."

By comparison, U.S. environmental and consumer groups have been curiously inward-looking. Americans mobilized to save the snail darter, yet have paid little attention to predictions that hundreds of thousands of species may become extinct in coming decades without having been catalogued, let alone studied for possible economic value or scientific interest.[16] Popular support is needed for research programs to survey and study existing flora and fauna in these areas, and ecologically sustainable strategies for their protection; in several poor countries these areas occupy much of the remaining unused arable land.

Public pressure might also be useful in convincing timber companies to adopt sustainable approaches to forest exploitation, even in countries where this approach may not be scrupulously required or even encouraged by local authorities. Such an approach might well be made unofficial U.S. government policy, and urged on U.S.-based companies—much as foreign policy officials occasionally urge financial support to a shaky government of special geopolitical importance.

The distinguished Dutch economist Jan Tinbergen has pointed out the natural alliance between consumer advocates in developed countries who seek to lower costs and improve the quality of products in the marketplace, and the advocates of increased trade with LDCs, whose products tend to be at the low-cost, low-quality end of the spectrum. Their combined efforts could lower prices of an entire array of products. Yet American consumer groups have thus far spent surprisingly little of their political capital in opposing protectionism. It is strongly in the interest of the American consumer both to insist on adequate measures to ensure innovativeness in American industry *and* to place no obstacles before—and in some cases to assist—the technological capacity of LDC industry.

CONCLUSIONS

A major expansion and redefinition of scientific and technological cooperation with the LDCs is needed, not only for humanitarian or charitable reasons, but to address major concerns of U.S. foreign policy for the 1980s: food, energy, global political stability, and the future of the world environment. The need for greater cooperation is especially acute in food, energy, and population. Effective bilateral and multilateral programs are already under way in food crop production research. These deserve continued support and expansion. In addition, there is an urgent need for international efforts to assist developing countries to develop indigenous sources of energy. Such a program could be readily designed and implemented.

While the urgency and importance of the population problem is no less acute, the priorities for international technological collaboration in this field are less clear and require further study. This should be carried out without delay so that effective action can be undertaken.

We have also identified needs for international scientific and technological collaboration in the study of parasitic and diarrheal diseases, and for the study of ecosystems of great economic potential, such as the humid tropical rainforest, which are in acute danger of disappearance. Finally, there is a general need to support local capability to mobilize science and technology at the national level as a part of overall national development.

While these suggestions, taken individually, may be relatively modest, they add up to a substantial redefinition of American attitudes and interests vis-a-vis the role of science and technology in foreign policy toward the developing world.

While scientific and technological cooperation along the lines suggested in this paper do not necessarily give rise to technological spectaculars, they do directly affect U.S. voter interests in lower food costs, freedom from petroleum cut-offs, secure supplies of minerals, the continued expansion of the world economy, and the expansion of world demand for technologically sophisticated U.S. equipment and services. They are essential parts of any strategy to eradicate the worst aspects of poverty and to conserve the global environment. They are important to any strategy to assist the long-run development of LDCs as a whole, or of such specific countries as the United States wishes to support for strategic or other reasons. And they are intrinsically challenging and exciting at a time when American popular interest is returning to scientific and technological advances.

These facts can be used as the basis for efforts to expand public support for scientific and technological collaboration with LDCs, as well as to gain support within the U.S. scientific and technological community for such work. Policies and programs based on shared long-term goals should complement, not replace, current policies based on humanitarian concern for the poor in developing countries.

There is a need to continue and in some cases to expand research on small-farmer agriculture, forestry, renewable energy, parasitic diseases, low-cost housing and sanitation, and other fields of specific interest to the poor. However, political support on this basis is palpably diminishing. In any case, purely humanitarian concerns do not provide a satisfactory basis for dealings with oil-exporting or middle-income developing countries, or indeed with the middle class of the poor developing countries who, after all, are the holders of political power.

There is no reason for LDCs to fear an American policy based on self-interest. On the contrary, this is their best reason to hope for a consistent policy. It is unreasonable and unrealistic to expect any country to pursue for long a policy which does not derive from its own interests. The incoming American administration has emphasized its intention to put U.S. interests at the center of its foreign policy.

A fully coherent and integrated policy toward the technological development of the developing countries no doubt must await the clarification of public attitudes toward the technological development of our own country. It would clearly be useful to build a consensus in this area, since the most important international technological issues vis-a-vis LDCs are but one aspect of a broader debate on the response of the United States to its interdependence with the rest of the world. This response requires a substantial effort to refurbish American competitiveness and innovative capacity, which in turn will require a major rethinking among labor, management, consumers, and the public. An interesting step in this direction was recently taken by the Economic Policy Unit of the United Nations Association of the United States, in its report entitled *The Growth of the U.S. and World Economies Through Technological Innovation and Transfer*.

The world of the 1980s is small, interdependent, and fragile. American security depends on economic stability and growth, here and abroad; a diversified supply of resources from many parts of the world; and preservation of the global environment. It also depends on relief of the misery of poor people, development of productive employment opportunities, and control of population growth. It may well be necessary to redefine public and official concepts of the national interest, which up to now have tended to refer primarily to military and strategic concerns.

All of these goals require that LDCs build the technological capacity to become full members of the international community. Their technological development deserves an important position on the foreign policy agenda of the United States. American resources are plentiful and can readily be mobilized. Although U.S. initiatives have achieved major impact, they continue to fall far short of efforts that should be undertaken in our own interest.

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5. John M. Kalbermatten, "Appropriate Technology for Water Supply and Sanitation: Build for Today, Plan for Tomorrow," lecture to the Institute of Public Health Engineers, 18 November 1980.

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7. Overcrowding by poor people in need of housing also poses a major danger to urban historical treasures, such as the great traditional Arab market of Fez, Morocco.

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9. A fuller definition of technology is given by the Economic Policy Association of the United Nations Association of the United States: "Technology means human knowledge used to achieve ends. Thus it includes everything from the manufacture of computers to the marketing of breakfast cereals, and from the use of public health measures to prevent disease to the growing of more abundant and better crops. It also includes the knowledge of how to organize society in order to achieve desired ends (corporations, educational institutions, health care organizations) and how to cope with related consequences." Economic Policy Council of the United Nations Association of the United States of America, *The Growth of the U.S. and World Economies Through Technological Innovation and Transfer* (New York: United Nations Association of the United States of America, Inc., 1980), p. 13. The author has defined technological capacity as: "The ability to make technological decisions that will influence the allocation of resources and the efficiency of production units. . . . [This goes well beyond technological infrastructure, by which term] we understand the public and private institutions which provide technical services for the selection, adaptation or creation of technologies, for pre-investment and project implementation work, for quality control and trouble-shooting in production processes and for technological managemen and planning both at the macro and the micro level." Charles Weiss, Mario Kamenetzky, and Jairam Ramesh, "Technological Capacity as an Element of Development Strategy," *Interciencia* vol. 5 (March-April 1980), p. 97.

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14. The proposed ISTC formed the centerpiece of the U.S. position at the U.N. Conference on Science and Technology for Development held in Vienna, Austria, in August 1979. U.S. participation in the conference was constructive and critical to even the modest degree of success achieved by that conference. The main tangible result of the conference was the creation of the U.N. Interim Fund on Science and Technology for Development, a multilateral fund to support the development of scientific and technological capacity in developing countries.

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16. Here a special exception must be made for the World Wildlife Fund, which is sponsoring a unique experiment in ecology to determine the minimum size of ecological reserve suited to the conditions of the Brazilian Amazon.

8 United States Agriculture in the Context of the World Food Situation

*Sylvan H. Wittwer**

INTRODUCTION AND BACKGROUND

Agriculture is the world's oldest and largest industry and its first and most basic enterprise.[1] More than half the people in the world live on farms. Food is first among our needs. Events of the past decade have focused attention on a new element of national power and safety—the control of vital resources, one of which is food. Renewable agricultural production will become increasingly important in resource bargaining. The potential of agricultural production as a strategic resource internationally and within the domestic economy is under review.[2]

The renewability of the products of agriculture comes as a result of "farming the sun." Agriculture, through the production of green plants, is the only major industry that "processes" solar energy. Green plants are biological sun traps. The aim of agriculture in crop production is to adjust plant species to locations, planting designs, cropping systems, and cultural practices to maximize the biological harvest of sunlight by green plants to produce useful products for people. Many products of agriculture may be alternatively routed as food, feed, fiber, or energy. Plants contribute to world food production 94 percent of the total edible dry matter by weight. Animals contribute 6 percent. Most animal products are derived in turn from plants.

Achieving an adequacy and security of food supply for all people is both a humanistic goal and a mark of progress. This paper focuses on science and technology as they relate to these goals, which are by no means easily managed or predictable. In the mid-1960s, for example, a two-year drought in India and Pakistan brought catastrophic shortages of food. The trend was reversed by a green revolution in the late 1960s. Poor harvests in 1972–1974, however, produced a new surge of despair. This was followed by a wave of optimism in the late 1970s brought by surpluses, low prices, and record production. Finally, in the early 1980s, we again face prospects of worldwide shortages and runaway food prices.

More than 70 percent of the current world population (4.3 billion) and 85 percent of the projected population growth by the year 2000, are found in the less developed countries. A large part (80 percent) of the absolute, as well as the relative, poverty is found in the rural and agricultural sectors. Many of the rural poor in developing countries are landless laborers or small farmers with insufficient land and capital to earn an adequate living from farming.

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Several hundreds of millions of people are chronically malnourished. More than half are children and more of them are women than men.[3] Food production must be increased considerably in the future or food and nutritional problems will become worse. According to the report of the Steering Committee for the World Food and Nutrition Study,[4] it will be necessary to increase food production by at least 3 to 4 percent per year between now and the beginning of the twenty-first century for significant improvement to occur.

These predictions are sobering in view of the trend during the 1970s for yields of the major food crops to reach a plateau both in the United States and in the rest of the world. Some of the possible causes for that leveling out have been outlined in the literature on the biology of crop production.[5] Meanwhile, energy intensive farm inputs have risen sharply and continue an upward trend. These are ominous signs because the timetable for doubling of food production to meet estimated consumption in most developing countries allows only 7 to 10 years.[6] The decades of the 1950s and the 1960s were truly the golden age for gains in American agricultural productivity (Figure 1). The yield fluctuations during the 1970s suggest that the consistent gains in the two previous decades are not likely to be repeated.

Increases in food demand will come from both growing populations and increases in consumer incomes. The major force in the growing commercial demand for food is rising affluence. Expanded productivity per unit land area, per unit time, and per unit cost is the primary source for the projected 3 to 4 percent yearly production increases needed. These increases, according to the Food and Agriculture Organization of the United Nations, could come from a 28 percent expansion of arable land—with a progressively decreasing portion in time—and 72 percent from intensification of land use through higher yields and increasing the number of crops produced per year.[7] In contrast, the *Global 2000 Report* projects that world food production will increase 90 percent over the 30 years from 1970 to 2000.[8] It also projects that arable land will increase only 4 percent by 2000 and that most of the increased food output will have to come from higher yields. The key to sufficiently large and sustaining yield increases will be technological change.

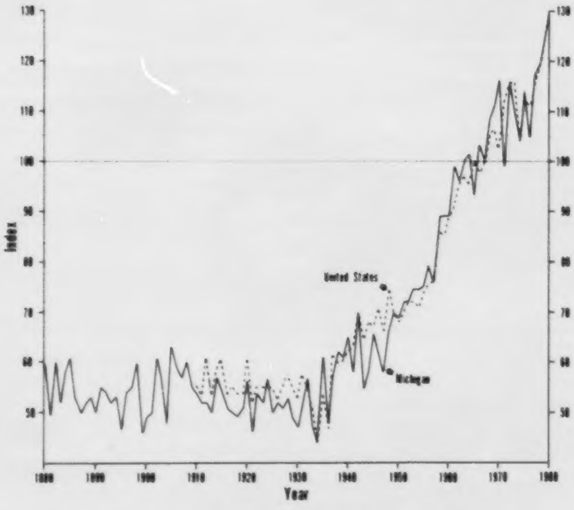

Figure 1. Composite Index of Crop Yields for the State of Michigan (1880–1980) and for the USA (1910–1980).

Note: There was no consistent gain from 1880 to 1940, there was a precipitous rise during the 1950s, and 1960s, and there was a tendency to plateau in the 1970s.
Source: Author, with the assistance of Karl T. Wright, Professor Emeritus of Agricultural Economics at Michigan State University.

The following scenario is likely: Larger populations, greater affluence, and increasingly greater consumption of animal proteins will intensify pressures for more intensive cultivation of available land. The pressure on land will be accentuated by the relative scarcity of water as its use approaches the limit of potential supply. The scarcity and expense of energy will then further aggravate the situation.

The challenge will be to "make two ears of corn or two blades of grass to grow upon a spot of ground where one grew before." (Jonathan Swift in *Gulliver's Travels*). This can be done by increasing traditional inputs, but at greater costs. The challenge will be to increase inputs at less cost, so that food prices can be maintained at reasonable levels. To achieve this policy strategy, one must take into account the resource inputs both natural (climate, land, water) and manmade (energy, fertilizer, pesticides, human labor, machinery). Their costs, availability, and renewability must also be taken into account.

In the United States the development of labor saving technology has been a significant goal and achievement. Never have so few people produced so much. A farm worker's production can be measured by the number of people, in addition to himself, he can feed. In 1980, one farm worker can feed 60 other people; in 1970 he could feed 30 other people; in 1940 only 10 others; and in 1900 only 6 other people. The increased productivity per unit of labor input may be attributed to more extensive and skillful use of the resources of water, energy, fertilizer, and pesticides. It is also the result of better management, more timely operations, and more efficient and productive equipment. Mechanization in the United States has enabled farmers both to carry out their field work on a timely basis and, at the same time, to allow for management activities. Mechanization in the United States has been a necessity because of the unavailability, uncertainties, and rising costs of human labor. In Japan and some other industrialized nations, where land, water, and energy resources have been limited and labor more plentiful, mechanization has not been as prevalent. In these countries, yields are higher, but output per farm worker is much less.

Thus, there are two general types of food production technologies for the future:

- food production, based on a high degree of mechanization, with extensive use of land, water, and energy resources, and little use of biologically-based technology.
- food production based on biological technology, and sparing of land, water, and energy resources.

The future will show a national and worldwide shift from a resource-based agriculture to one based on biological and scientific technology. The emphasis will be to raise output for each unit of resource input, and to ease the constraints imposed by relatively inelastic supplies of land, water, fertilizer, pesticides, and energy.

REASONS FOR THE SHIFT TO BIOLOGICALLY-BASED AGRICULTURE

Ruttan has pointed out that the shift to a biologically-based agriculture has already occurred during the first part of the twentieth century in Japan and certain European countries.[9] Whereas the United States has followed a mechanical-resource intensive technology, Japan has followed a biologically- and chemically-based technology which is sparing of resources. Incentives for increasing yield technologies have lagged until recently in the United States, compared to Japan and some European countries, because of the abundance and low cost of resources in the United States. But this situation is bound to change in the United States and elsewhere. It is projected that almost all future increases in food production will be a result of increases in yield (output per unit land area per unit time) and from growing additional crops during a given year on the same land. There are really no other viable options.

Any new agricultural technologies for the future will combine more dependable production and higher yields, and will emphasize strategies which are more labor-intensive than capital-intensive, and which spare rather than exploit resources. They must be nonpolluting and scale neutral (adaptable to any size of farm). They must offer solutions to global food problems (Table 1), and increase the demand for underutilized labor resources. Technologies of this sort already exist. Some will be described later.

One of the constraining myths in setting the food research and technology agenda for the future is the belief that all we have to do is put to use the technology we now have and all will be well. This implies that we do not need more research but only better dissemination of the results of research already completed. Nothing could be farther from the truth. The agricultural research establishments—both privately-supported and public— of America and other industrialized nations have focused on large-scale single crop or livestock operations and labor saving technologies that are intensive in capital, management, and resources. The changing cost of energy, however, is undermining all our previous assumptions about the costs and feasibility of increasing agricultural production, and much of the technology of agricultural production as well. No longer can we plan research programs patterned after the conventional ones or those of the past.

Table 1—Global Problems and Agricultural Productivity

Poverty
Inflation
Malnutrition
Underemployment
Deforestation
Soil erosion
Changing climate
Population increase
Shortage of firewood
Water-logging and salinization
Uncertainties of energy supplies
Toxic chemicals in the environment
Improving production and yield stability
Grain-food/energy conflicts
Communication gap between agriculturists and policymakers
Uncertain responses of political institutions

Source: Author.

We must now develop more diversified resource-conserving technologies for agricultural production. These technologies must maximize output for a given set of inputs, optimize labor utilization, and minimize capital costs for development. To be useful, they must improve the economic conditions of farmers. Nations with predominantly small farms must find ways of transmitting new technology to many farmers. This places a great responsibility not only on research programs, but also on extension and education.

Environmental issues will become more important as more land, water, fertilizers, and pesticides are diverted to food production to force higher productivity. We can expect greater use of chemicals as new technologies are applied. The greatest potential for increases in food production is in the developing countries, and it is in just these countries—mostly tropical and semitropical—that fertilizer needs are greatest and pest problems most acute.

Conflicts in the use of land and water resources for food, feed, or fuel production will continue as resource constraints intensify.[10] Toxicities from airborne materials and projected climate changes from fossil fuel emissions will direct attention to the production and use of renewable resources.

Food production is the chief user of our land and water resources. Toxic chemicals in the environment, some of them pesticides and fertilizers used for food production, have been declared hazards to human health and well-being. Debates will continue on issues of food safety, deleterious effects of chemicals on fish and wildlife and their habitats, endangered species, and carcinogenicity. Although some people have tried, no one has yet clarified what an environmentally sustainable set of agricultural production technologies might be. We must address this issue with more than just debates that result in polarization. This will require a substantial research investment.

Recent history is filled with apocalyptic prophecies of world hunger, famine, and starvation. The recently released report of the Presidential Commission on World Hunger, for example, infers that the food production situation is worsening, and that we are farther from the goal of reducing hunger and malnutrition than we were in 1974. The report presents little evidence, however, to support this statement.[11] Other equally dismal reports ignore prospective scientific discoveries and remain skeptical about major breakthroughs in production. The unfortunate consequence of this pessimism is that without hope there may be little action. Far from achieving scientific or biological limits, however, scientists have only begun to explore the capabilities for increasing food production. Basic and applied research can stimulate future governmental and private sector efforts to increase the stability of production and expand food supplies.[12]

Leadership for the resolution of food production problems through research and technology will continue to reside with the United States. The United States now produces, consumes, and exports more food than any nation in all of history. Sixty-one percent of the grain which crossed international borders in 1979 was grown in the United States. Agricultural exports for 1980 approximated 41 billion and offset more than three-fifths of the cost of imported oil. Serious questions have been raised about whether the high U.S. agricultural production can be sustained, especially with the current massive resource inputs. The issue is whether continued, abundant, low-cost foodstuffs can be provided.

U.S. AGRICULTURE AND THE WORLD FOOD SITUATION

Recognizing that there will be approximately 6.2 billion people on the earth by the year 2000, national strategies must meet increasing demands for improved nutrition and more animal protein, keep food prices reasonable for everyone, and lessen tensions among nations. The United States, with its vast human and natural resources, occupies a unique position. Other nations no longer take U.S. supremacy in food and agriculture for granted, yet, they continue to come to our doors in search of new food producing technologies. The United States cannot and should not plan as a long-term policy to be the bread basket of the world. This would require an exploitation of land, water, mineral, and energy resources that neither we nor the rest of the world can afford for long, if for no other reason than that the price for increasing inputs will likely become prohibitive. The United States, more than any other nation, has already used up its geologic endowment.[13] Because it is energy intensive, long-distance, massive food transport, cannot be viewed as a viable long-term alternative to producing food closer to the people who consume it. Several developing countries already have "pockets of success" which employ adaptive sets and combinations of western and domestic technologies.

Great care and restraint should be exercised in using food as a strategic resource. The effects are not always predictable, humane, or effective. As the recent grain embargo attempt with the Soviets shows, this kind of strategic use of food penalizes primarily—and perhaps, only—the poor and farmers. Nevertheless, adequate food supplies can alleviate unrest and tensions among nations and peoples. The U.S. food system faces both domestic and foreign demands that are largely interdependent. Both the balance of payments and exchange of raw materials for value-added goods among the United States and industrial and nonindustrial countries are crucial to the economies of all. Foreign demand on the U.S. food system comes from two different sources: developed or industrialized nations and less developed countries. Food exports from the United States are now going primarily to the industrialized nations and serve mainly to increase the availability of dietary animal protein. In the process, the less developed countries are being largely ignored. It is not likely that this situation will change quickly. Such a global dichotomy will persist.

The objectives of U.S. agriculture in the context of the world food situation should be to continue:

- providing a dependable, adequate, safe, and nutritious food supply for its domestic needs;
- assisting both industrialized and developing nations, through food exports;
- sustaining a livable environment.

Humanitarian considerations, alleviation of stresses among nations, marketing of surpluses, achieving a balance of payments, and needed exchange of materials dictate these objectives. To achieve them, a reassessment of investments in U.S. food and agricultural production research and educational programs, which have progressively eroded for the past 13 years, will be required. The situation has become even more critical during the past four years, since the U.S. Department of Agriculture (USDA) began elevating consumer and nutrition concerns (food safety, quality, nutritional content) to the highest priority, while deemphasizing food production and marketing research.[14]

THE U.S. AGRICULTURAL RESEARCH SYSTEM

Food and agricultural research is managed differently in the United States than in other countries. State governments, responding to the aggressive actions of research administrators and scientists at universities, are largely responsible for food and agricultural research. It is the state governments, not the federal government, which provide the bulk (approximately two-thirds) of the money and human resources, establish their own directions, set their own priorities, develop the most innovative approaches on research frontiers, and take the initiative in sponsoring foreign agricultural development programs. This stands in marked contrast to research conducted in the defense, space, health, energy, and regulatory areas, which is managed largely by federal agencies.

While there has been a long standing partnership between the U.S. Department of Agriculture and the agricultural experiment stations of the states, that bond is slowly being eroded by a progressive subordination and attrition of cooperative research within the federal system. (One needs only to observe the offices they occupy.) Research has not been a major mission within the U.S. Department of Agriculture, although some progress has been made during the past two years. More and more financial responsibility for food research is falling upon state governments.

At the same time, the federal agricultural research system is rapidly disintegrating. Few vacancies are being filled and 40 percent of the career scientists are eligible for retirement within the next five years.[15] The average age of career scientists in the federal agricultural research system is now 49 and increasing by a third of a year per year. There are progressively fewer young scientists. The system also has been subject to constant personnel attrition; the scientific force having been reduced from 3,300 to 2,850 during the past five years. Meanwhile, new waves of interest and concern—food safety, environmental problems, regulatory constraints, human nutrition, excessive reporting—have been imposed on the research system. Limitations on travel to professional meetings and on funds for operations, imposed by a budget which must allot up to 90 percent of the total financial resources to salaries, provide little incentive for bright young scientists to enter the system.

The United States Agency for International Development (AID) suffers a similar shortage of agricultural scientists, with only about 300 full-time agricultural positions now remaining.[16] This is shocking if we consider that AID's fiscal year 1979 budget allocated $669 million to agricultural development and nutrition. Thus, only 10 percent of AID's staff is professionally competent to handle agriculture, which is 55 percent of its budget.

Since the early 1970s the purchasing power of federal support of agricultural research has been declining at the rate of 2 percent per year. Of all federal agencies, the USDA with its cooperative support of state agricultural experiment stations has been the only one in the executive budget severely disadvantaged by cuts during the past three years. Final outlays for agricultural research and education in 1980 were 0.3 percent less than the previous year, compared with an average 7 percent gain in federal funding for other types of research and development. Less than 2.3 percent of the total federal research budget of approximately $30 billion was directed to food and agricultural research in 1980, while global outlays for total research and development for agriculture have averaged 3 percent.[17] We are letting our own national agricultural research system erode while other nations develop theirs. The Congress should intervene immediately to correct this situation.

The United States and the world continue to underestimate and demean the importance of investments in agricultural and food research. Viewed as an investment, with annual returns of 50 percent or more, agricultural research does not receive adequate support in the United States. Two causes have been suggested: first, the benefits of agricultural research spill across countries, states, and regions to those who do not pay for it; and second, benefits to consumers often are not apparent to them.[18]

We should continue to encourage parallel efforts between state and federal support of agricultural research. A decentralized system that addresses the needs of individual states will more than compensate for apparent duplication of effort. Any centralized system designed to achieve maximum coordination among states will only neglect specific regional and state problems and will come at a high price.

Funding of food and agricultural research must include expenses for maintaining and replacing research tools, even when they are not currently being used. These tools include: flocks, herds, barns, feed, milking parlors, machinery, field stations, land, orchards, crops, irrigation equipment, and greenhouses. Much of the formula ("Hatch") money traditionally allocated for agricultural research goes into the maintenance of this kind of equipment. As a result, critics repeatedly allege that agricultural research is inefficient compared to the competitive grant programs administered by the National Science Foundation (NSF), National Institutes of Health (NIH), or—under new legislation—by the USDA. Even though indirect charges are included, these competitive grants do not pay the ever-rising maintenance and replacement costs for machinery, cattle, orchards, crops, land, water, labor, and energy. University business offices, however, have seen to it that overhead charges from competitive grant funding pay for on-campus bookkeeping offices, lights, heat, and water. This means that agricultural research in universities requires supplementary funding to survive.

Agricultural research in the state agricultural experiment stations is slowing down, not only because prices rise while federal support falls, but because facilities (laboratories, greenhouses, barns, and equipment) are woefully inadequate and outmoded. In addition, facilities remain cramped, because student loads have increased three-fold in 12 years. Yet little federal support has been provided for renovation and improvement of facilities in 15 years, and none since 1970.

Except for maintenance, as outlined above, requests for across-the-board increases for all agricultural research disciplines are no longer convincing. The message, however, is clear: both competitive grant and formula funding of food and agricultural research should go up, but priorities have to be set for not only the amounts but the kinds of research to be pursued.

FOOD PRODUCTION RESEARCH PRIORITIES

The food crisis of 1973–1975 and the oil embargo have created new priorities for food and agricultural research. Future research will focus on ways of controlling the biological processes that limit the productivity of economically important food crops and food animals. Research goals will also include more effective use and management of resources and other production inputs.

The national or international working conference model has been an effective means of establishing priorities in agricultural research. The best scientific talent with a range of interdisciplinary skills is recruited. Commissioned papers on specified topics are prepared and distributed to prospective participants in specified working groups in advance of the conference. After a week's revision and further development during the conference, the results are edited and published as proceedings. An executive summary sets forth the priorities.

Assessments of research priorities for the plant and animal sciences have been elaborated in an international conference on crop productivity,[19] several reports of the U.S. National Research Council—National Academy of Sciences,[20] a national conference on Animal Agriculture—Meeting Human Needs for the 21st Century,[21] and by the Office of Technology Assessment of the U.S. Congress.[22] The World Food Conference of 1976 also outlined research priorities.[23] A working conference sponsored by the Agricultural Research Policy Advisory Committee of the state-federal system, established research priorities by a ballot system from a large number of participants.[24] The International Conference on Agricultural Production—Research and Development Strategies for the 1980s—issued recommendations for research and development in biological resources, soils, water, and energy.[25] Within the past three to five years, public and private agricultural and food research centers, from provincial to international levels, have reassessed and identified research priorities. These centers have sponsored long-range planning seminars on the major issues and trends of agricultural science and technology. From all of these efforts, a surprising unanimity has emerged.

BIOLOGICAL RESEARCH AND FOOD PRODUCTION

Through research, scientists could develop technologies that would result in stable food production at high levels. These technologies would enhance rather than diminish the earth's resources. They would not pollute the environment, or use large amounts of capital, management, or nonrenewable resources. They would be scale neutral. Development of these technologies is of the highest priority, and can be accomplished through biological research. Through biological research, we can take steps toward enabling plants and food animals to use present environmental resources more effectively. Through biological research we can achieve:

(1) greater photosynthetic efficiency;
(2) improved biological nitrogen fixation;
(3) genetic improvements;
(4) more resistance to competing biological systems (weeds, insects, diseases);
(5) more efficient nutrient and water uptake and utilization, and fewer losses from nitrification and denitrification of nitrogen fertilizer applied in crop production;
(6) alleviation of climate and environmental stresses (unfavorable temperatures, soil moisture, and mineral stresses in problem soils);
(7) better understanding of hormonal systems and their regulation.

These technologies may release food production from dependence on increasingly scarce fossil fuels.

Efforts to identify these important research areas have not resulted in expanded research support, but they have prompted changes in organization, administration, and funding of agricultural research at the federal level. A notable example has come with the initiation of the competitive grant program administered by USDA. This infant program which supports the first four of the research areas listed above, was initiated in 1978. Announcement of the $14-million program brought in more than 1,100 research proposals involving funding requests for more than $200 million. Available funds could support only half the proposals rated as excellent. Similar situations existed in 1979 and 1980.

All of this has revealed one important fact. There is enormous talent waiting to be recruited for viable research programs related to the biological processes that control food production. Nevertheless, during the young life of the competitive grant program, now in its fourth year, Congress has consistently limited funding of the program to essentially the same level, denying the program even those increases needed to offset the effects of inflation. The minimal increase allowed has been eaten up in administrative costs. The available human resources revealed by the number of applicants with excellent project proposals heralds an opportunity for this nation to reassert the world leadership that it has abdicated in the area of food research. A policy which severely limits funding, however, denies to agricultural and food research programs the talents of some of the very best scientists in the nation. This cannot be reconciled with our true national interest. It is time we opened the door of agricultural and food research to the nation's scientific expertise including that possessed by the private sector.

The benefits of support for the competitive grant program would be reaped by the developing countries as well as by the United States. Developing nations can share in the benefits of the new technologies we have already discussed—improved plant and animal genetics, increased photosynthetic efficiency and nitrogen fixation, as well as protection against insects, diseases, weeds, and adverse environments. These technologies can free developing nations as well as the United States from an ill-advised dependency on fossil fuels for food production. The research necessary to create these new technologies is adaptable to local conditions and is relatively inexpensive.[26]

Benefits from such research could be multiplied many times, and advances made by one nation could be shared by others. Genetic pools could be assembled, for example, so that nations could share information about known favorable components for disease resistance, environmental stress tolerance, a superior "harvest index" (the portion of the plant used for food), and acceptable culinary characteristics that can be adapted quickly to local needs and conditions.

A particularly significant, yet neglected biological research area, is the alleviation of climatic and environmental stresses. The report of the Steering Committee for the National Academy of Sciences World Food and Nutrition Study, issued in 1977, deemed this as important as improved photosynthesis and biological nitrogen fixation, genetic manipulation, and protection against pests. The effects of climate and weather remain the most significant determinants in food production and account, more than any other inputs, for instabilities in production from year to year and from nation to nation.

Stability of production is as important as the magnitude of production itself. Climate is probably a more significant determinant of food production than pests. The droughts of 1974 and 1980, for example, caused far greater losses of U.S. agricultural production than the blight which destroyed 15 percent (or about 700 million bushels) of the U.S. corn crop in 1970. In 1974, production plummeted 20 percent for corn, wheat, and soybeans as a result of drought. In 1980, corn production fell 17 percent from 1979 or 1.3 billion bushels; grain sorghum 32 percent; feed grains 18 percent; soybeans 22 percent; cotton 23 percent; and peanuts 43 percent.

Climatic stresses on world grain production were particularly significant in 1980. That year, the composite index of crop yields in the United States (Figures 1 and 2) dropped 20 percent because of drought and high temperature. Grain production fell off in the People's Republic of China because of floods in the south and drought in the north. The Soviet Union witnessed its second disastrous year in a row because of marginally cold and dry growing conditions and adverse weather during harvest. Only in South Asia did production rise slightly above previous highs (Figure 2). These statistics suggest that world and U.S. grain stocks will be reduced, relative to utilization, to the lowest levels encountered in two decades.

A substantial research effort aimed at improving the resistance of crops to stresses caused by interannual climate variations is badly needed. While potential problems of long-term climate change—for example, from

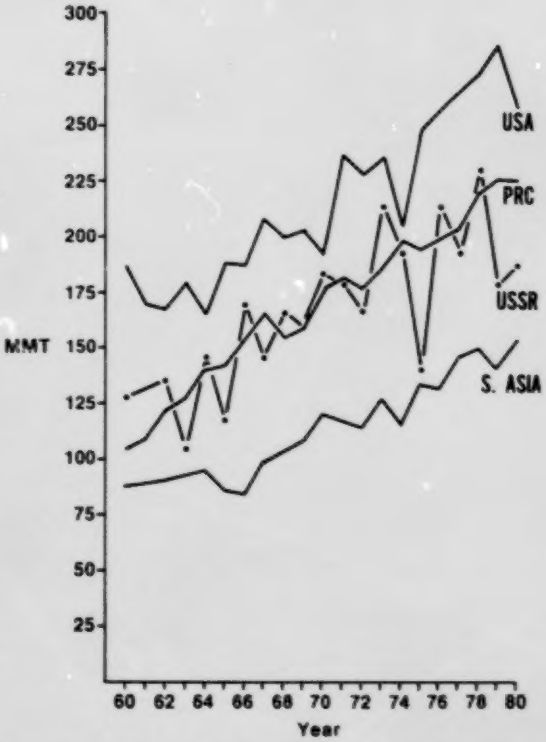

Figure 2. Patterns of World Grain Production in Millions of Metric Tons (MMT).

Note: For the United States (USA), People's Republic of China (PRC), Soviet Union (USSR), and South Asia (S. Asia) from 1960 to 1980. Perturbations in the upward trends are primarily a result of climatic and weather events. The extreme variations in the USSR result from millions of hectares of land that are marginally cold or dry. The relative stability of production in China and South Asia results from a high percentage of crop irrigation. Climatic stresses during 1980 will result in a severe depletion of grain stocks and storage reserves.
Source: U.S. Department of Agriculture, and personal correspondence.

increasing levels of atmospheric CO_2—have received considerable attention in recent years, problems of interannual climate variation have been largely overlooked. Research directed at achieving greater production stability through genetic improvement and crop and livestock management is of high priority. The USDA's competitive grant program must be expanded to accommodate this kind of research, and the Congress should respond accordingly.

Some new research initiatives are also called for in animal agriculture and its products. Three-fourths of the dietary protein, one-third of the energy, and most of the calcium and phosphorus in the U.S. diet come from animal products. Food animals, such as ruminants, are living, mobile, protein factories that may survive and flourish on forages that are indigestible for people. Food animals like swine and poultry use residues and byproducts from food processing and from the polycultures of lakes and ponds that otherwise would be wasted. The world food reserves in livestock exceed those of grain and are far better distributed.

The feeding of livestock in other nations is the catalyst for much of the current U.S. world grain trade. Livestock, not people, consume most of the corn, wheat, and soybeans the United States ships abroad. Peoples of all nations, developed and less developed, are striving for more dietary animal protein. Research in animal agriculture should focus on resource conservation, greater reproductive efficiency, and basic studies on protein synthesis that would result in less fat and more protein in the final product.

HUMAN RESOURCES FOR AGRICULTURAL RESEARCH

Consideration must be given to human resource needs for food and agricultural research and technology. We have already mentioned the serious loss of career scientists in the federal agricultural research system. Mention is often made of the lack of social science inputs into the nation's agricultural research program. An almost exclusive responsibility for agricultural research training programs in the United States resides with the land grant universities, a few additional state universities, the colleges of 1890, and the Tuskegee Institute. These institutions train scientists for research in state agricultural experiment stations, the USDA's research programs, cooperative state-federal programs, the private sector, the foundations, and the international agricultural research centers. The 15 top land grant universities, with enrollments of 100 or more foreign graduate students, have now produced 20,000 alumni helping to serve agricultural research and educational needs in developing countries. These alumni are one of the greatest resources this nation has cultivated for contributing to the future role of U.S. agriculture in the context of the world food situation. Most of the 10,000 to 12,000 U.S. agricultural scientists who receive public support, and an even greater number from the industrial sector, plus many of the more than 600 senior scientists in the international agricultural research centers are also alumni of the U.S. land grant system.

The human resource base for scientific support of food research in the United States now has fallen behind the Soviet Union and the People's Republic of China.[27] In the United States, shortages of trained scientists are emerging in agricultural economics, agronomy, engineering, and animal agriculture. The United States can expect increasing demands, both at home and abroad, for training and aiding agricultural scientists. These demands call for a review of the entire training program and raise serious questions about where international agriculturists will come from.[28] The National Science Foundation is responsible for the health of science in the nation. It must reassess its role in supporting the biological, physical, and social sciences in research on food production and distribution, and in supporting foreign graduate students for training programs in agriculture and food production.

INTERNATIONAL AGRICULTURAL RESEARCH CENTERS

Globally, the most successful agricultural research establishments are the international centers. They have undertaken innovative research projects for enhanced food production and other aspects of agriculture, and have prospered. Annual funding for these centers (now numbering 13) has gone from $10 million in 1969 to more than $125 million in 1980, with $250 million projected for 1984. The United States continues to contribute about 25 percent of their total budget which, along with other sources of income, is administered by the Consultative Group on International Agricultural Research with advice and scientific input from its Technical Advisory Committee.

Recent congressional and administrative proposals are aimed at consolidating all foreign research and technology activities, along with many other programs, under a new International Development Cooperation Agency (IDCA). This agency would include the Institute for Scientific and Technological Cooperation (ISTC), which would have a strong input from U.S. colleges and universities. This institute would have responsibility for science and technology efforts in developing countries relating to food and agriculture. The current Collaborative Research Support Programs (CRSPs) would then fall under the administration of ISTC.

An appropriate constituency has not yet been developed either in Congress or in the nation to support ISTC or expanded international agricultural development programs.[29] Approximately half ($50 million) of the proposed 1981 budget of ISTC would have focused on food, nutrition, and agricultural programs in other nations with primary focus on developing countries. Congressional opinion, however, does not support federal programs for food and agricultural research directed toward the needs of other nations.[30]

This lack of support is puzzling in view of the benefits we ourselves can derive from international involvement. Most of our major food crops and breeds of livestock and much of our technology have been derived from other countries:

- dwarf—high yielding—varieties of wheat and rice from Japan,
- soybeans from China,
- insect resistant wheat from Russia,
- new genetic resources for third generation hybrid corn from South America,
- high vitamin A sorghum from West Africa,
- high protein, high lysine wheat from Nepal,
- cattle more tolerant of heat, parasites, and insects from Africa and Asia.

These are by no means the only benefits to be derived from other countries. The production of Zebu (Brahma) cattle from the Asian subcontinent, has created an entirely new beef industry in the higher temperature regions of the southern United States in less than 20 years. The most advanced genetic material for dwarf hybrid sunflowers resides in the Soviet Union. Future collaboration with the People's Republic of China is expected to make available vast genetic resources in swine breeding, cereal grains, oil crops, and many yet undeveloped fruits and vegetables. The Chinese also have much to offer in Azolla culture (green manuring through biological nitrogen fixation) and hybrid rice production.

Congress should review carefully what is emerging from the Collaborative Research Support Programs (CRSPs) which are administered by the Board on International Food and Agricultural Development. Teams of U.S. economists and other social scientists are participating in interdisciplinary and inter-university programs committed to research design and implementation. They are collaborating on both basic and applied research with similar groups from developing countries. The major objective of such programs is more effective resolution of a wide variety of staple food problems, including production, utilization, and the socio-cultural impacts resulting from them. It is implicit in the CRSPs that research will emphasize technologies that do not exploit resources, pollute the environment, or depend on large energy inputs. Biological solutions will be emphasized, wherever possible, over reliance on costly and possibly polluting agricultural chemicals. This kind of research may be significant to U.S. agriculture as we move toward a more resource-conserving mode.

It is expected that the benefits of the research will have a global impact incorporating U.S. interests, because we have been active in planning strategy from the outset. Established efforts involving collaboration among U.S. institutions, international research centers and commodity networks, and national research centers include programs on field beans/cowpeas, sorghum/millet, small ruminants, integrated pest management, and aquaculture. One of the most advanced of the CRSP efforts is the field bean/cowpea program which has locations outside the United States, including 12 research institutions in Latin America and East Africa and two international agricultural research centers. The program involves ten U.S. universities and brings together many disciplines, including agronomy, botany, genetics, plant pathology, entomology, food science, human nutrition, medicine, and social science. Managed by Michigan State University and guided thus far by a sociologist and a plant breeder, the program's initial contract calls for $16.7 million for a five year period.

Challenges ahead for the CRSPs will be to seek funding at the federal level for up to 50 percent of the U.S. investigators' time. The current support level of about 10 percent is disproportionate for the managing institution and cannot survive. There should be an effort to train counterpart scientists in the developing countries and to promote regional centers for training intermediate level technicians and extension personnel, both men and women. CRSPs can help bridge the gap that now exists between international agricultural research centers and national programs. They can help develop and hold together global research teams on specific problems. Through these collaborative efforts it is hoped that recognition will be given to inputs from cultures where the solutions are to be used. Many peasant farming practices are also worthy of research, and some may have useful applications for U.S. agriculture.

The role of the international agricultural research centers is under constant review,[31] and should go beyond inputs from the Consultative Group on International Agricultural Research. Major early breakthroughs, such as occurred with dwarf types of wheat and rice, characterized their early development. Gaps now exist between the international centers and national agricultural research centers. To bridge these gaps will require closer collaboration in the future between the two. The international agricultural research centers are not yet truly international, because much of the world is not a part of the networks either as contributors or recipients. The international agricultural research centers also exhibit and exercise a degree of research affluence (higher salaries, benefits, equipment, supporting personnel, travel opportunities) not typical of the countries in which they are located. It is unlikely that any of these problems will be overcome soon.

It is recognized that the international agricultural research centers have, in some instances, upgraded national agricultural research centers. The National Institute for Agricultural Research in Mexico is a good example.

Emphasis in the future should be on the increased support and development of national agricultural research centers. Most food production problems are regional and solutions must be localized. There is a movement toward this with the establishment of the International Agricultural Development Service and the International Service for National Agricultural Research, the most recent member of the international agricultural research network.

It is further recommended that the Consultative Group on International Agricultural Research take the initiative in establishing two international research centers for forestry. One center should be located in the tropics, with Brazil, Indonesia, or Africa as possible sites; the other in the temperate zones of either North America or China. Attention should be given to enhancement of forest productivity through genetic improvement and management. Special emphasis would be given to biomass as a renewable energy resource, reforestation and control of soil erosion, trees and their products as food resources, and the technologies of agriforestry utilizing species that have biological nitrogen fixation capabilities.

CONCLUSION

The United States cannot indefinitely serve as the breadbasket of the world. Food production and its delivery along with fossil fuel energy will become increasingly expensive, and at times both food and energy will be scarce. Agricultural development must precede economic development. Ultimately, the answer will dictate that food be produced closer to the people who consume it. To this end, there are notable examples of successful food producing systems in the agriculturally developing world. Some of them are summarized in Table 2. The technological, social, economic, and resource ingredients that have gone into these pockets of success should be identified and shared with other nations where their adoption could prove equally fruitful.

Table 2—Pockets of Successful Production in Developing World Agriculture.

Projects	*Accomplishments*
Grain Production in India's Punjab	A 3-fold increase in grain production in 10 years from 1965 to 1975
Rice Production in Colombia	Yields rose from 1.8 to 4.4 tons/hectare from 1965 to 1975
Wheat Production in Turkey	Increase in production from 7 to 17 million tons from 1961 to 1977
Hybrid Rice in China	30 to 50 percent yield increase (labor intensive high yielding technology)
Hybrid Cotton In India	Yields doubled (labor intensive high yielding technology)
The White (Milk) Revolution in the Gujarat State of India	Daily cash income, improved nutrition, labor intensive technology for 300,000 small farms
The Puebla (Maize) Project in Mexico	Yields increased by 30 percent from 1968 to 1972
The Comilla Project of East Pakistan (Bangladesh)	Rice yields and incomes of farmers doubled from 1963 to 1970
The "Masagana 99" Project in the Philippines	Rice yields increased by 36 percent in 3 years from 1973 to 1976
Maize in Kenya	Hybrids and fertilizer and management increased yields 4.8 tons/hectare
Hybrid Maize in the U.S.	3.5 fold increase in yield from 1940 to 1979

Source: Author, and S. Wortman and R.W. Cummings, Jr., *To Feed This World: The Challenge and the Strategy* (Baltimore: Johns Hopkins University Press, 1978), pp. 186–230.

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9 Trends and Prospects in World Population

*Michael S. Teitelbaum**

INTRODUCTION

Population trends form the basic substrate of concerns about resources and international comity over the coming decades. The links between population change and the other matters under discussion here often are not single and direct, but instead are mediated by a broad array of political, technological, and economic factors. The extraordinary force of recent population change, however, should not be minimized. Present trends have no precedent in human experience in terms of current population size, percentage rates and absolute size of increase, and ultimate projected population size. Hence projections into the future, apart from the normal limitations of all projections, represent leaps of faith into population aggregates that are off the scale of experience.

RECENT POPULATION TRENDS

This is not the place for an introduction to demography or for a lengthy review of recent population trends, but a brief summary is in order.[1] Three components of population change are central—fertility, mortality, and migration. Each of these components is measurable (with greater or lesser accuracy), and each has distinctive effects upon the characteristics of human populations on a global, national, and subnational basis.

The post-war period has seen substantial, sometimes dramatic, mortality declines in both developed and developing countries. In developed countries there have also been more erratic changes in fertility patterns, with most showing post-war recovery from the record-low fertility levels of the 1930s (the so-called Baby Boom in the United States was an extreme example). The post-war recovery was followed almost universally by rapid fertility declines in the 1960s and 1970s, reaching levels that are now frequently lower even than those of the 1930s.

A different set of patterns prevailed in the developing countries. In some countries, notably China, Taiwan, the Philippines, Tunisia, and Colombia, mortality declines have been followed by substantial fertility declines during the 1960s and 1970s from previously very high levels. In other countries, such as Bangladesh, Pakistan, and Egypt, fertility has declined little, if at all. In still other countries, such as Kenya, fertility apparently has increased dramatically. The overall result has been acceleration in population growth in much of the developing world, followed by modest recent declines in growth rates in some areas. The experience over the past three decades may be seen in Table 1.

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The world's population increased by 1.9 billion, or over 75 percent, in the three decades from 1950 to 1980, as Table 1 indicates. The annual rate of increase was at a then-record level of 1.77 percent in the 1950–1955 period, but actually accelerated sharply in the ten years to 1960–1965, peaking at 1.99 percent (Table 2). This was followed by a slower decline in the rate of increase, to a level of 1.81 percent in 1975–1980—lower than the peak rate, but still higher than the 1950–1955 quinquennium.

Because the higher percentage rates of economic growth, inflation, or interest are more familiar than demographic rates, it is important to keep recent population growth rates in a proper demographic perspective. Sustained annual population growth rates of 1.8 to 2.0 percent have never before been seen for the world population as a whole. Because of continuous compounding, they imply a doubling of world population every 35 to 39 years. They fit within a frame in which the theoretical maximum growth rate—assuming excellent mortality conditions and no restraint on fertility—is on the order of 4.0–4.5 percent. (By contrast, inflation and interest rates presumably have no upper bound.)

There is reason for concern that the fertility declines of the past 15 years have been widely misinterpreted as evidence that problems of rapid population growth have been resolved.[2] The achievements in fertility reduction in the 1960s and 1970s were significant indeed, but so were the achievements in mortality reduction. As a result growth rates declined only modestly, from about 2 percent to about 1.8 percent. The problem of high population growth rates has not been resolved in the past decade. Rather the trend has reached a point of inflection. The rate of increase itself is no longer increasing, but instead has declined modestly, though remaining at extraordinarily high levels by all past human experience.

Table 1—Population (millions) in the Eight Major Areas of the World, 1950 to 2000.

Year	World	Africa	Latin America	Northern America	East Asia	South Asia	Europe	Oceania	Soviet Union
				Estimates					
1950	2513	219	164	166	673	706	392	13	180
1955	2745	244	187	182	738	775	408	14	196
1960	3027	275	215	199	816	867	425	16	214
1965	3344	311	247	214	899	979	445	18	231
1970	3678	354	283	226	981	1111	460	19	244
1975	4033	406	323	236	1063	1255	474	21	254
1980	4415	469	368	246	1136	1422	484	23	267
				Projections					
1985	4830	545	421	258	1204	1606	492	24	280
1990	5275	630	478	270	1274	1803	501	26	292
1995	5733	726	541	281	1340	2005	510	28	302
2000	6199	828	608	290	1406	2205	520	30	312

Note: Trends are given as they were assessed in 1978. 1980 data are projections from mid-1975 data, but may be viewed as best available estimates for 1980.
Source: W. Parker Mauldin, "Population Trends and Prospects," *Science*, vol. 209 (4 July 1980), p. 156.

Table 2—Average Annual Rate of Increase (percentage) in the Eight Major Areas of the World, 1950–2000.

Year	World	Africa	Latin America	Northern America	East Asia	South Asia	Europe	Oceania	Soviet Union
				Estimates					
1950 to 1955	1.77	2.16	2.72	1.80	1.85	1.86	0.79	2.25	1.71
1955 to 1960	1.95	2.36	2.78	1.78	1.99	2.24	0.84	2.18	1.77
1960 to 1965	1.99	2.49	2.77	1.50	1.94	2.44	0.90	2.09	1.49
1965 to 1970	1.90	2.61	2.67	1.11	1.75	2.52	0.66	1.96	1.09
1970 to 1975	1.84	2.71	2.64	0.87	1.62	2.45	0.61	1.82	0.84
1975 to 1980	1.81	2.91	2.66	0.83	1.32	2.49	0.39	1.47	0.94
				Projections					
1980 to 1985	1.80	2.97	2.65	0.96	1.16	2.44	0.36	1.41	0.94
1985 to 1990	1.76	2.93	2.58	0.91	1.14	2.31	0.35	1.37	0.85
1990 to 1995	1.66	2.81	2.46	0.76	1.01	2.13	0.37	1.30	0.70
1995 to 2000	1.56	2.64	2.34	0.61	0.95	1.91	0.38	1.19	0.64

Note: Trends are given as they were assessed in 1978. 1980 data are projections from mid-1975 data, but may be viewed as best available estimates for 1980.
Source: W. Parker Mauldin, "Population Trends and Prospects," *Science*, vol. 209 (4 July 1980), p. 156.

Furthermore, it must be noted that the absolute size of population growth is as important as percentage increase, and here a few numbers illustrate the uniqueness of the past decades. The population of Asia alone in 1980 (2.558 billion), for example, is larger than the entire world population in 1950 (2.513 billion). A population of 730 million—about as large as the combined 1980 populations of Northern America and Europe (excluding European portions of the Soviet Union)—was added to the already existing population of South Asia in only 30 years (an increase of 716 million from 1950 to 1980). Many similar comparisons could be made to illustrate the extraordinary demographic experiences since World War II.

Table 2 provides a useful retrospective view of regional growth rates. Africa and Asia show clear patterns of accelerating growth rates in the 1950s and 1960s, while the other regions were more mixed. Since the 1960s most regions have experienced substantial declines in their rates of population increase. The very large region of South Asia, however, shows no such decline, and the smaller region of Africa shows a rapid and continuing increase in rate of increase right up to the present.

The third population change component—migration—appears to be of large and rapidly increasing magnitude. There have been, over the past decades, increasing movements within countries from rural to urban areas. In the developing world urban growth rates are about twice as high as the already high national growth rates. These rapid growth rates suggest unprecedented urban agglomerations appearing over the coming 20 years.

International migration, including legal or illegal, political or economic, temporary or permanent, has also grown rapidly. Both internal and international migration have important, if elusive, implications for issues of resources and international relations. Movement of rural populations from subsistence economies to more energy-intensive urban areas, for example, presumably implies higher per-capita energy needs. Similarly, large migrations from developing countries to developed countries suggest greater overall demand for food, mineral resources, and energy.

POPULATION TRENDS IN PROSPECT

It must be freely admitted that population projections do not predict, but rather represent the logical implications of assumed future trends in fertility, mortality, and migration. Population trends, however, are relatively stable as compared to the political and economic, due to a three-part, built-in inertia in demographic change to the year 2000. First, the majority of persons who will be living then are already alive; second, human reproductive behavior changes relatively slowly; and third, high fertility generates a youthful population with strong momentum for continued growth over many decades. As a result, the demographer can predict trends with reasonable accuracy over several decades, though not much beyond. Projections of population change to the year 2000, in contrast to those for economic or political change, have considerable plausibility barring unpredictable catastrophes.

The conventionally accepted multinational population projections are those prepared periodically by the United Nations Population Division; others are available from the World Bank and the U.S. Bureau of the Census. Given demographic inertia, available projections to the year 2000 are broadly compatible. The medium variant of the widely accepted United Nations projections is summarized in Table 2. It shows a projected gradual decline in world population growth rates of about one-quarter of one percent, reaching 1.56 percent overall in 1995–2000. At the same time, the rapidly growing population base means that the numbers of people added each year will continue to grow—to about 90 million additions per year in 1995–2000 vs. about 75 million annually in 1980, despite the projected decline in growth rate.

The three variants in United Nations projections show a total world population in 2000 of 5.9, 6.2, and 6.5 billion. Most other projections cluster around 6 billion. Again using the medium variant, overall growth of 40 percent (1.78 billion) is projected, with regional increases of 77 percent in Africa (359 million), 65 percent in Latin America (240 million), 55 percent in South Asia (783 million), 24 percent in East Asia (270 million), 18 percent in Northern America (44 million), 17 percent in the Soviet Union (45 million), and 7 percent in Europe (36 million).

The momentum of population growth in the developing countries is likely to continue, although projections beyond the year 2000 are quite speculative. No one can anticipate the course of fertility change in high fertility regions of South Asia and Africa, where fertility has not yet begun to decline. For this reason, and because catastrophes are possible but unpredictable, there is some consensus as to the plausible range but none as to the ultimate size of the world's population. Assuming no serious mortality increases or widespread disruptions, projections vary from 8.5 billion to 13.5 billion or even higher. The lower bound assumes, unrealistically, that the world as a whole will reach replacement fertility, approximately the two-child family, within 20 years. The projection of 13.5 billion assumes replacement fertility in 2040–2045.

Recent trends in urban growth, as we have already noted, suggest future urban concentrations unprecedented in human experience. The United Nations recently published revised projections of urban populations up to the year 2000. The projection approach is "state-of-the-art," but the authors note that the magnitudes projected go beyond our experience and may not prove reasonable if human agglomerations of such size cannot be sustained. Despite this appropriate caveat, the projections are instructive (see Table 3).

The projections show five cities larger in 2000 than the largest human agglomeration ever experienced. Twenty-year increases of between 75 percent and 131 percent are projected for seven cities in developing countries, including Mexico City, Sao Paulo, Beijing, Rio de Janeiro, Greater Bombay, Calcutta, and Jakarta. As the United Nations staff notes, some of the projected numbers, e.g., the 31.0 million for Mexico City, may not be attainable due to water supply problems, destruction of tree cover, transportation difficulties, and other "natural or social limits to growth."[3]

Whether or not such magnitudes are attained, the growth of cities in many developing countries seems certain to be rapid, with consequent stresses on food and water supply, building materials, energy, and so on. There are also likely to be repercussions for political organization and stability.

In the developed countries, with fertility already very low and the bulk of the population already using contraceptives, speculations about the future become more hazardous. United States fertility in the 1980s is expected to stay low by some experts[4] and by others[5] to rise dramatically. In the 1930s in Europe, fertility as low as that in much of the developed world today produced exaggerated alarms about national decline that culminated in a profusion of pronatalist policies. Similar policies in much of Eastern Europe in the 1960s sometimes led to coercive childbearing, as the means of voluntary fertility control were denied. Whether such extremist responses occur, as for most political behaviors in the future, cannot be reliably predicted.

If fertility does stay low, and international migration is moderate, we can predict demographic effects with considerable accuracy. There will be a gradual increase in the average age of the population of such countries, and a shifting of the "dependency burden" from non-productive children of school age to non-productive adults of post-retirement age. As a result, more national resources will have to be allocated to the larger elderly group, and fewer to the smaller young group.

Table 3—Projected Population Increases in Major Cities, 1980–2000

City/Region	Projected Pop. 2000 (Millions)	Estimated Pop. 1980 (Millions)	Change/ % Increase
Mexico City	31.0	15.0	+107%
Sao Paolo	25.8	13.5	+91%
Tokyo/Yokohama	24.2	20.0	+21%
New York/N.E. New Jersey	22.8	20.2	+13%
Shanghai	22.7	14.3	+59%
Beijing (Peking)	19.9	11.4	+75%
Rio de Janeiro	19.0	10.7	+78%
Greater Bombay	17.1	8.4	+104%
Calcutta	16.7	8.8	+90%
Jakarta	16.6	7.2	+131%

Source: United Nations Population Division, *Urban, Rural, and City Population, 1950–2000, as Assessed in 1980*, ESA/P/WP.66 (3 June 1980), p. 38.

LINKING POPULATION TRENDS TO OTHER PROBLEMS

Population trends underlie all of the other problems under consideration here, though the links are not as direct or unmediated as sometimes claimed. The linking of population growth to food shortages has a long and controversial intellectual history, dating back at least to the essays of the Reverend Thomas Robert Malthus in the first half of the nineteenth century. In retrospect, we may conclude that Malthus' concepts were partially correct, but his predictions quite wrong. Technological and other improvements have allowed food production to more than keep up with the unprecedented growth of world population. Yet in principle, population cannot continue to grow indefinitely in a finite world, and signs of resource shortages and environmental stresses are already apparent.

Several theoretical efforts have been made to calculate the maximum human population sustainable by the world's agricultural resources, but such calculations often are highly stylized—even mechanistic. They consider arable land availability on a global basis, whereas in fact land is available only within sovereign nation states. They adopt idealistic assumptions of high average agricultural productivity, equal distribution of world food supply, and a worldwide diet equal to that of Japan. They take into account no regional limits on water supplies or difficulties in moving surplus water from one region to another, no political or economic limitations on world commerce, and no shortages of energy or fertilizer supplies. In short, these calculations contradict reality in fundamental ways. At the same time, their realism content is enhanced by their assumption of no dramatic quantum improvements in agricultural productivity. Were such completely unpredictable improvements to occur, they would counterbalance the unreality of the other assumptions.

The most recent effort to project population trends in relation to global resources is the *Global 2000 Report to the President*, produced by the Council on Environmental Quality. This three-year project sought to integrate a series of projections in various related sectors up to the year 2000, including: climate, technology, food and agriculture, fisheries, forestry, water, energy, fuel minerals, nonfuel minerals, and environment. The enterprise presented enormous technical and data problems, and its authors were forthright in admitting that they were only partially successful. In particular, they were unable in the time available to them to make the various projections fully interactive, so that changes in one sector could have full feedback effects in the other sectors. The report's authors conclude that the overall impact of these deficiencies is to "understate the severity of potential problems the world will face as it prepares to enter the 21st century."[6]

Despite these deficiencies, the *Global 2000 Report* presents some interesting findings. It notes correctly that the momentum of population growth means that only moderate differences in population size by the year 2000 are possible depending on the course of fertility in the coming two decades. The report makes the following projections (1) Gross National Product (GNP) will grow more rapidly in developing countries than in developed countries. (2) Because of the lower starting point and the more rapid population growth in the developing countries, however, per capita GNP increase in these countries will remain very modest in both absolute and relative terms. (3) Some developing countries, especially in Latin America (and presumably some OPEC nations), will improve significantly in per capita GNP, although others will make few if any gains from present low levels. (Increases in India, Bangladesh and Pakistan, for example, are projected at 31%, 8%, and 3% respectively, with all three countries remaining below $200 per capita in 1975 dollars.)[7] As a result of these trends, the report projects increasing per capita income disparities between the wealthiest and the poorest nations.

With regard to food supply, the *Global 2000 Report* summarizes its alternative projections with the cheering proposition that food production can continue to slightly exceed population growth up to the turn of the century, assuming no deterioration in climate or weather conditions. To achieve such growth, however, food production will require increasing inputs and technologies of a yield-enhancing, energy-intensive nature such as fertilizer, pesticides, herbicides, and irrigation. Such increased energy dependence of agricultural production has significant implications for the cost of food production, and the report projects a substantial increase in real food prices over the coming two decades, after decades of generally falling prices. Food production and consumption is projected to continue to be highly varied among the world's regions and nations, with rising food output of developing nations barely keeping ahead of rapid population growth. Furthermore, the high percentage of income already spent on food by hundreds of millions of people in poor countries suggests disturbing implications were the report's projected sharp increases in real food prices to take place.

Two points deserve comment here. First, in many developing countries government policies seriously impede increased food production. In some countries, development policies provide direct or indirect subsidies to nonfood production, but deny credit and other needed resources to food producers. Other countries use price controls on food products to keep urban consumer prices low and thereby stabilize the political structure; but such well-meaning controls may also produce losses for farmers and encourage rural-to-urban migration. Coupled with rapid population growth and unfavorable climatic trends, such policies have led to declines in per capita food production in some developing countries over recent years, especially in Africa.

Second, it may be reasonably argued that global figures on food production are misleading, because the overwhelming bulk of food production is consumed locally. Efforts by the Food and Agriculture Organization to build a world food reserve have not yet succeeded, and even the large volume of international trade in foodstuffs constitutes only a small proportion of total food production. Hence, the primary goal of policy and technological innovation must be enhanced food production within the countries where demand is increasing rapidly, with international trade providing only marginal or emergency supplies.

LINKING OF POPULATION TRENDS TO INTERNATIONAL SECURITY ISSUES

The AAAS Five-Year Outlook project mandates consideration of the relationships between population trends and international security issues. The literature on international relations contains a number of common hypotheses which oversimplify this complex issue:

- The larger a nation's population, the greater its actual or potential power.
- Population pressure on natural resources contributes to pressure for international aggression to obtain additional such resources.
- Nations with excessive population densities seek "living space" or "elbow room" via international aggression.[8]

Empirical analyses of international conflicts do not support most of these hypotheses. In general, population size and density appear to be underlying factors that may or may not contribute to international conflict. Much depends upon mediating political, social, and economic factors, including stability of national political structures, distribution of available resources, technological and capital base of the nation, human capital available, and patterns of consumption.

On the other hand, it is a truism that nothing can grow infinitely in a finite world. If population growth continues, it eventually will exceed the social, economic, and political capacities of some nations. Hence, a summary assessment might be that eventual restraint on population growth is not a sufficient condition to assure internal and international stability, but that it is a necessary condition.

Problems of international conflict often are generated by internal instabilities within nations, as recent experiences in the Middle East demonstrate. Hence, it is also important to consider the effects of population change on internal stability as it relates to international relations. In this regard, several demographic trends demand attention. The first is the unprecedented rapidity of demographic change in many developing countries since World War II. A nation with a very substantial resource base may be able to support a much larger population, but if population size increases very dramatically, the rate of increase rather than the population size itself may contribute to instability.

A second component of high fertility is the distortions in the age composition which it engenders. High-fertility populations are also youthful populations, with typically 45 percent or more of their populations under the age of 15. Apart from the obvious problems such a concentration of young people presents for educational and other age-related services, such a steeply sloping age structure implies a very rapid growth in entrants into the labor force each year. The International Labour Organization projections, for example, show increases of 600 to 700 million in the developing world's labor force in the next twenty years alone. To put these numbers into perspective, such an increase over two decades is larger than the entire 1980 labor force of the whole of the developed world.[9] In many developing countries already experiencing very high rates of unemployment and underemployment, such a rapid growth of young labor force entrants presents serious problems which can spill over into political instabilities. Such problems are further compounded in many of these countries by very rapid rates of rural-to-urban migration which contribute to even more rapid rates of labor force growth in urban areas.

Given the near certainty of rapid labor force growth in developing countries for the remainder of this century, labor-intensive development policies, especially in the rural areas, represent an important component of efforts to maintain national coherence and internal stability. To the extent instability and dissolution in such countries spill over into the international sphere, as happened recently in Iran, policies favoring intensive and broadly based job generation also favor international security interests. Although developing countries themselves must make any decisions favoring such policies, developed countries such as the United States can make these policies more attractive and feasible, through trade and tariff policies that favor imports produced in labor-intensive industries. International political support can also encourage governments to move toward such domestic policies.

IMPLICATIONS FOR U.S. SCIENCE AND TECHNOLOGY

Science and technology have already contributed impressively to recent population trends, and can be expected to continue to do so. The rapid acceleration of population growth in developing countries after World War II owed much to improvements in health, nutrition, and sanitation, due in some (perhaps great) measure to science and technology. The sustainability of the so-called population explosion (which in fact bears more resemblance to a speedy glacier than to a bomb) owes much to the improved productivity of agriculture and technological innovation as well as the capacity to convert abundant energy resources themselves (also a product of technological innovation) into edible calories.[10] Equally important were improvements in technologies of significance to public health, ranging from sanitary water systems, to biologicals such as vaccines, to improvements in internal and international communication and transportation that diminished the deadly impact of localized food shortages.

Improvements in communication and transportation have also contributed to internal and international migration. Isolated rural populations discovered the relative attractiveness of life in urban areas or in other countries by listening to transistorized radios and watching television programs brought to them by communication satellite. At the same time, the improvement of internal road, rail, and air networks have facilitated movements to the urban areas, and the increased availability and declining real price of international air travel following the development of modern aircraft technologies has sharply reduced the nonlegal barriers to international migration. Finally, the availability of satellite communication has brought vividly to the attention of the world the plight of millions of miserable refugees starving and dying on the high seas or in temporary encampments. In the way that television is said to have affected perceptions of the war in Vietnam, so too has it changed public images of refugee problems.

Science and technology have also contributed greatly to fertility declines. While some form of fertility control has been available in most human societies, it is often forgotten that highly effective contraception is a development of only the past 20 years; the first oral contraceptives were not widely marketed until the early 1960s, and the IUD was not widely available until the same decade. Similarly, safe and acceptable male sterilization via vasectomy (the most popular fertility control method in some countries) did not become common until the 1970s, although tubal ligation for females was in use earlier. There have also been substantial reductions in the health risks of induced abortion due to technological advances.

Finally, science and technology have also contributed greatly to our collective understanding of population change and its impacts. Demography and some of the social and statistical sciences have, over the past 30 years, provided new and powerful tools by which we are now able to detect and estimate demographic rates—in some respects analogous to the technologies that have improved our capacities to assess agricultural potential, measure air and water quality, and even predict the weather. Such demographic tools now allow indirect estimation of demographic rates among populations whose births and deaths are not registered and in nations that in some cases have never conducted an adequate census. Other important scientific advances have contributed to our understanding of the factors affecting age composition and the momentum of population growth, the patterns of marriage behavior, and the relationships of mortality change to fertility behavior.

THE OUTLOOK

As to future contributions, the capacity of world agriculture to accommodate to projected 40 percent increases in population in 20 years will depend heavily upon the contributions of both U.S. agricultural production and scientific expertise. Similar contributions can be made on the mortality side, via intensive work on tropical diseases that continue to be large-scale killers and maimers, such as river blindness, schistosomiasis, diarrheal diseases, and cholera.

With regard to fertility, it is evident that the array of contraceptive methods presently available, while a substantial improvement over those before 1960, are inadequate to the needs of large numbers of people and nations. As has often been pointed out, oral contraceptives are relatively nonspecific in their modes of action, and have side effects that make them inappropriate to the needs of many people desiring effective fertility control. Intrauterine devices (IUDs) equally have notable limitations (in fact their mode of operation is but little understood), and available sterilization methods are less acceptable than they would otherwise be because they are substantially irreversible.

Furthermore, the diversity of social, economic, cultural, and religious settings in the world today means that a method that is highly preferred in one setting may be unacceptable in another. Even within societies, individuals require different contraceptive techniques; indeed the same individual requires a variety of methods through his or her lifetime—a useful illustration of the diversity of contraceptive demands. If we define "marital" to include stable consensual unions, we can describe four stages of the individual's reproductive life cycle:[11]

(1) Premarital;
(2) Delay (post-marital, pre-first birth);
(3) Spacing (post-first birth, before completion of fertility);
(4) Completion of fertility.

The contraceptive characteristics most suitable for each of these stages are presented in Table 4. Such variety of individual needs, coupled with the diversity of national, religious, and cultural settings, suggests that there can be no such thing as "the ideal contraceptive"; what is required is an array of methods with differing attributes, collectively providing an adequate scientific and technologic response to the needs presented by human diversity.

Contraceptive technology advanced greatly in the 1960s, but little since, and there are few promising methods on the immediate horizon. The scientific and technological pipeline is a particularly long one in the field of fertility control, given the appropriate concern of governmental regulators as to the safety of methods that may be used by millions of healthy young adults. Over the next five to ten years, only a few potential improvements are in prospect—a sub-dermal implant for slow release of contraceptive hormones may prove effective and safe, and some improvements may be made to existing IUD technology. While science and technology often confound the most reasonable predictions, there are at present no great anticipations of new methods to fill some of the obvious gaps: effective male contraceptives other than condoms, and reversible methods of voluntary sterilization. The problems are not in the realm of technology or product development, but rather result from our very limited understanding of the remarkably complex process of human reproduction. Yet in the recent past, scientific attention to this area has been modest; the study of human reproduction, prominent in the 1930s, nearly died out in the 1940s, and had to be resurrected in the 1960s. As a result, it is a johnny-come-lately that remains a minor claimant on government research resources.

In spite of vigorous rhetoric to the contrary, available evidence shows that the overwhelming majority of third world people live in countries whose governments openly declare their desire to lower rapid rates of population increase. In the most recent survey by the United Nations (in 1978), such countries comprised fully 82 percent of the population of the developing world, including most of the largest (for example, China, India, Indonesia, Bangladesh, and Pakistan). A relatively larger number of nations with small populations, especially in Latin American and sub-Saharan Africa, however, reject the need for such a demographically oriented policy. Hence the one-nation/one-vote structure of the United Nations and other international forums sometimes conveys a less prominent commitment to reducing rapid

Table 4—Characteristics of Contraceptives Related to Life Cycle Stage.

Stage	Characteristics
1. Premarital	Relatively irregular and infrequent exposure. Intercourse-related methods (particularly postcoital) somewhat more acceptable than in delay and spacing stages. Serious consequences for contraceptive failure. Limited knowledge of and access to fertility control. Limited independent access to medical system, hence nonmedical delivery is preferable. Reversibility highly important.
2. Delay: Postmarital, Pre-first birth	Frequent exposure. Relatively moderate consequences for contraceptive failure. Relatively short period of protection required. Methods where application is independent of intercourse are highly desirable. High acceptability and convenience important. Method delivery via medical system is less undesirable than in premarital stage due to readier access to medical system. Reversibility highly important.
3. Spacing: Post-first birth, Precompletion	Frequent exposure. Moderate consequences for contraceptive failure. Long time span (as sum of separate birth intervals) of protection required. Reversibility somewhat less important than in delay stage.
4. Completion of wanted fertility	Long time span of protection required. Less frequent exposure than in delay and spacing stages. Serious consequences for contraceptive failure. Intercourse-related methods somewhat more acceptable than in delay and spacing stages. Acceptability and convenience less important than in earlier three stages. Reversibility less important than in three previous stages.

Note: Characteristics discussed here are *average* characteristics and need not apply to any particular individual in any stage.

Source: Roy O. Greep, et al., *Reproduction and Human Welfare* (Cambridge, Mass. and London: MIT Press, 1976), p. 71.

population increase in the developing nations than is in fact the case.

The ability of developing countries to lower their population growth rates as a matter of public policy depends heavily upon improved knowledge of the social, economic, and cultural factors favoring fertility decline, and on improved skill in implementing service programs that must reach literally millions of couples. The causal mechanisms underlying past fertility declines are imperfectly understood, even for the now developed countries. Existing governmental strategies aimed at encouraging fertility decline range widely:

- development policies aimed at enhancing presumed indirect factors favoring fertility decline (Egypt);
- policies for directly providing knowledge and means of fertility regulation (India, China, Mexico, Bangladesh, and Indonesia, to name a few);
- the use of economic and other incentives affecting individual fertility behavior (Singapore, China);
- official support for direct application of "pressure" or "persuasion" (China).

If future policies are to be more effective, there is much to be learned about the impacts of such an array of strategies in diverse settings, and the tools of social science and evaluation research are the only means for such learning. Such efforts can be highly cost-effective, as a modest research investment can result in substantial improvement in the implementation of expensive large-scale programs, and can suggest new or additional strategies that may prove more effective in a given social, economic, or cultural setting.

It is commonly believed, and often pronounced, for example, that declines in infant and child mortality are both necessary and sufficient to lower fertility; hence in many settings population policies concentrate heavily on maternal and child health services. Scientific evidence on this question, however, is mixed. Historical analyses of the European fertility transition suggest that mortality declines were not consistently important explanatory factors.[12] Evidence from developing countries suggests that fertility response to infant and child death is only partial,[13] and may be larger in some settings than in others.

Equally unknown is the nature of factors that have led to dramatic increases in marriage age that in some countries have accounted for a large percentage of birth rate declines. Enhanced understanding here could provide new and effective policy levers for government officials.

Finally, knowledge of the pattern, magnitudes, and causes of internal and international migration is notoriously deficient; as these population movements grow in size and impact, it is evident that coping with them will require the illumination that comes only with scientific analysis.

United States scientific and technological innovation ranks high as both initiator and moderator of recent population problems. Many of the effects of rapid population growth are only now coming to be felt, as the large surviving generations born in the 1960s and 1970s reach adulthood and seek employment and lives of human dignity. It seems certain that meeting these human needs and moderating present rapid rates of population growth will require enhancement of U.S. scientific and technological contributions over the coming decades.

NOTES AND REFERENCES

1. For an authoritative yet concise assessment, see W. Parker Mauldin, "Population Trends and Prospects," *Science*, vol. 209 (4 July 1980), pp. 148–157.

2. See, for example, the controversy and reportage that followed publication of Army Ong Tsui and Donald J. Bogue, "Declining World Fertility Trends, Causes, Implications," *Population Bulletin*, vol. 33 (September 1978).

3. United Nations Population Division, *Urban, Rural, and City Population, 1950–2000, as Assessed in 1980*, ESA/P/WP. 66 (3 June 1980), p. 57.

4. Charles F. Westoff, "Marriage and Fertility in the Developed Countries," *Scientific American*, vol. 239 (December 1978).

5. Richard A. Easterlin, *Birth and Fortune* (New York: Basic Books, 1980).

6. U.S. President, Council on Environmental Quality and U.S. Department of State, *The Global 2000 Report to the President* (Washington, D.C.: U.S. Government Printing Office, 1980), vol. 1, p. 7.

7. Ibid., p. 13.

8. See U.S. House of Representatives, Select Committee on Population, *Population and Development Assistance*, 95th Congress, Second Session (December 1978), pp. 20–22.

9. International Labour Organization, *Labour Force Estimates and Projections, 1950–2000*, Second Ed., vol. 5 (Geneva: 1977), Table 6.

10. As an indication of how rapidly perceptions can change, it is worth recalling that only a decade or so ago there were popular and scholarly discussions of developing new technologies by which cheap petroleum from the Middle East could be converted directly into edible proteins during tanker shipment.

11. Roy O. Greep et al., *Reproduction and Human Welfare* (Cambridge, Mass. and London: MIT Press, 1976), pp. 68–73.

12. Ansley J. Coale, "The Demographic Transition Reconsidered," *Proceedings of the International Union for the Scientific Study of Population* (Liege: 1973), pp. 53–72; and Michael S. Teitelbaum, "Relevance of Demographic Transition Theory for Developing Countries," *Science*, vol. 188 (2 May 1975), pp. 420–25.

13. See, for example, Samuel H. Preston, ed., *Effect of Infant and Child Mortality on Fertility* (New York: Academic Press, 1977).

10 International Security Implications of Materials and Energy Resource Depletion

*William A. Vogely**

INTRODUCTION

Materials and energy depletion have been continuing fears of mankind since the industrial revolution. Throughout the nineteenth and twentieth centuries, thoughtful observers have warned of the ultimate exhaustion of the materials and energy resources upon which society is based. Classical economists predicted a steady state of no growth, and labor at subsistence wages. In 1866 Stanley Jevons wrote in the preface to the second edition of *The Coal Question:*

> Renewed reflection has convinced me that my main position is only too strong and true. It is simply that we cannot long progress as we are now doing—not only must we meet some limit within our own country, but we must witness the coal produce of other countries approximating it to our own and ultimately passing it . . . our motion must be reduced to rest, and it is to this change my attention is directed.

Jevons' words, in a different context, are echoed in 1972 in the introduction to *The Limits to Growth:*

> If the present growth trends . . . continue unchanged, the limits to growth on this planet will be reached sometime within the next 100 years. . . . it is possible to alter these growth trends and to establish a condition of ecological and economic stability that is sustainable far into the future.[1]

The subject of materials depletion is an extremely broad and multifaceted one. This paper limits itself to looking at the implications of materials and resource depletion for international security. Thus, it will ignore many interesting and important areas, such as conservation and environmental issues concerning the production and use of materials and energy. It will, however, look at the process of resource depletion in order to state clearly the nature of the depletion problem.

THE PROCESS OF RESOURCE DEPLETION

Resource concepts are semantically difficult because the terminology used to describe resources is confusing and the same words mean different things to different people. The literature is full of resource life indexes which divide resource stock by either annual or cumulative production based upon an annual rate of growth, and measure the number of years remaining to each resource before it is exhausted. These indexes misunderstand, perhaps deliberately, the nature of resource supply. Whether presented with sophistication and understanding or presented in ignorance, the resource life indexes represent a fundamental misstatement of the problem of depletion. Resources flow into the economy—they are not an inventory to be used over time.

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Depletion of a natural resource occurs at three distinct levels: (1) single deposits; (2) the replacement of deposits in the production function; and (3) at the ultimate occurrence of the resource in the earth. Much of the misunderstanding about resource terminology has occurred because words derived from one of these levels are applied to another level.[2]

DEPLETION OF A RESOURCE DEPOSIT

Natural resources occur in nature in deposits which have unique chemical, physical, and locational characteristics. Some deposits of mineral resources are economic to produce in relation to the markets for their product. These deposits may be developed into producing sites: mines, if the resources are solid; or fields, reservoirs, or wells, if the resources are liquid and gas. A known deposit that is capable of being produced today is called a reserve. These reserves will be produced through time from the deposit. The deposit may be extended through exploration; the reserves, through additional capital investment. Material produced from that deposit, however, will not be replaced in the deposit, thus the deposit will begin to be depleted as it is produced. Depletion of a deposit simply means that for every ton produced there is one ton less left to produce. As a single deposit is used up, the cost of production from the deposit tends to increase. The deposit is considered "depleted" when it is no longer economically attractive to continue production. The deposit will then be abandoned and, some would say, it is exhausted.

It is important to note, however, that virtually no resources have been physically exhausted. For a typical oil field, an average of over 60% of the original oil remains in the deposit upon abandonment. In the case of the nonfuel resources, mine sites are abandoned because the remaining ore does not justify further investment to develop it. But if the investment again becomes worthwhile, the oil field or mine site may be reopened. With high prices of gold, for example, hundreds of abandoned mine sites in the West are being opened, and with the increased price of oil, abandoned wells are also being produced.

Reserves are determined and measured in terms of a specific deposit. Deposits are abandoned for economic reasons, and not because their contents are literally exhausted or reduced to zero.

REPLACEMENT OF DEPOSITS

Except in geologic time, the distribution of energy and materials in the earth's crust can be taken as fixed. In this distribution, deposits come in all sizes, shapes, grades, and chemical characteristics. These deposits are discovered through exploration. The deposits that are profitable to develop become producing mines and contain reserves. As it ceases to be economically attractive to extract resources from a deposit, that deposit is replaced by a new one. New deposits are discovered by investment in exploration, and become producing mines through further investment. The replacement of deposits is a function of exploration and of investment to develop the deposit. Deposits frequently remain undeveloped because the economic cost of developing them is not attractive, given the markets for the commodities. Thus, deposits are replaced either when a new, economically attractive deposit is discovered or when technologies for developing known deposits at an attractive cost are developed.

At this second level of consideration depletion can be said to be occurring when the replacement deposits are of higher real cost per unit than the depleted deposits that they replace. This is the aspect of depletion that has been discussed most thoroughly in the literature. In their path-breaking book, *Scarcity and Growth,* H.J. Barnett and C. Morse tested the process of depletion of replacement deposits by positing that if it were occurring, the real costs or real price of materials should be rising through time.[3] They were not able to prove this hypothesis and in fact found that such real costs were declining in the period of 1870 to the 1950s. Recent work by V. Kerry Smith and others has weakened that conclusion with respect to the period following the 1950s.[4] It is depletion in this sense, however, which underlies most of the literature with respect to resource exhaustion.

DEPLETION OF THE RESOURCE BASE

All of the elements in the upper earth's crust, water, and atmosphere are considered the resource base. It is theoretically impossible to deplete these resources. Mankind is only able to redistribute, not destroy them. In the case of the nonfuel resources, production concentrates them from their natural occurrence and, in a sense, creates new mines from which they can be reclaimed through recycling. In the case of the energy resources, use does reduce the energy potential contained in those resources and, in that sense, increases the entropy within the universe. Clearly the forces of geologic processes are to level the earth, and in time the energy flow will reach an equilibrium state of zero. The time spans for such events, however, are well beyond the projected and possible survival of mankind.

From a global point of view, resource deposits in nature can be ranked by the cost of producing them under any given state of technology. Such a ranking, although impossible to quantify, would present a picture of a stepwise increase in cost as resources with different economic dimensions are used. At one end of the spectrum would be the resource content of sea water or of common rocks, the supply of which is "inexhaustible." The cost of obtaining any given mineral element from these ultimate resources may be infinitely high; but these resources are, nevertheless, physically inexhaustible.

SUMMARY

As Zimmerman has pointed out, "resources are not, they become."[5] The principles we have sketched underlie the current orthodox classification of resources along the double axis of economic availability and geologic identification. The current resource classification system used by the federal government, presented in Figure 1, illustrates these concepts. This basic idea of resource categorization has many variants, and, of course, there is much discussion concerning what kind of numbers to put in the various boxes. The process of resource depletion is both an economic and a geologic phenomenon. It is economic in the sense that any deposit will be abandoned when continued production is no longer economically justified; the replacement of that depleted deposit depends both on geologic occurrence of deposits and the economics of additional capacity; and finally, the limit on further production is always an economic, not a geologic, phenomenon.

THE CONCEPT OF RESOURCE ADEQUACY

The concerns expressed by the authors quoted in the introduction relate not to exhaustion as a phenomenon but to the fact that a decline in resource availability to mankind will impose real limits to the quality of life of mankind. This concern, which broadens the scope of the analysis from the economics and geology of resource deposits, raises the problem of resource adequacy. By definition, adequacy must be measured in terms of objectives. Thus, the subject of resource adequacy has both a supply and a use side. Several general measures of resource adequacy have been proposed. T. Page, for example, suggests that we use constant costs of resource availability through time as a test of resource adequacy. V.K. Smith tries to develop a scarcity index of resource adequacy.[6] Others define it more narrowly, in terms of resource adequacy for a three year war, as defined by government policy with respect to strategic stockpiles. Still others look at resource adequacy from the point of view of whether a given resource is adequate to allow society to undertake actions to replace its use with another, which is the current underpinning of energy policy with respect to liquid fuels. All of these concepts have a common analytical structure. They involve adequacy as measured by supply with respect to an objective or demand for the resource. Adequacy always has a supply and a demand side.

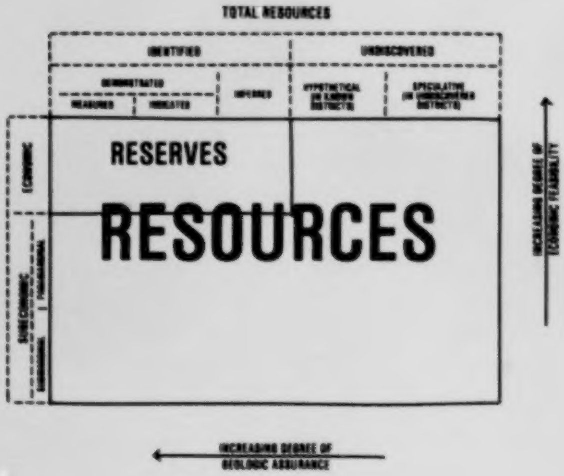
TOTAL RESOURCES
IDENTIFIED
UNDISCOVERED
DEMONSTRATED
MEASURED
INDICATED
INFERRED
HYPOTHETICAL (IN KNOWN DISTRICTS)
SPECULATIVE (IN UNDISCOVERED DISTRICTS)
ECONOMIC
SUBECONOMIC
PARAMARGINAL
SUBMARGINAL
RESERVES
RESOURCES
INCREASING DEGREE OF ECONOMIC FEASIBILITY
INCREASING DEGREE OF GEOLOGIC ASSURANCE

Figure 1. Classification of Mineral Resources.

THE SUPPLY SIDE OF ADEQUACY

Virtually all analyses of the supply side of adequacy start with some measurement of the size of the various resources categories shown in Figure 1. As we have already noted, transformation of resources to reserves is the fundamental issue on the supply side of resource adequacy. Recognizing this, we see at once that the critical variable is the quantity of reserves that can be ultimately developed, given the economic costs. But this quantity is unknown and, at the current state of our knowledge, unknowable. All attempts to estimate what R.G. Ridker and W.D. Watson call "prospective reserves" involve the application of the current state of human knowledge to predict or project unknown quantities.[7] There are three primary methodologies being used to make such estimates.

The most familiar method relates the remaining volumes of prospective reserves to the rate with which reserves have historically been developed and used. These time rate methods flow from the pioneering work of King Hubbert, and they indicate a limited prospective reserve category for oil and gas, uranium, and some other major mineral commodities.[8] A second technique uses a geologic or geographic analogy whereby the material and fuel content of a known geologic environment is assumed to be replicated in all such geologic environments in the earth's crust, or in a more general sense, the material and energy content of a given geographic area is assumed to be replicated in other equal-in-size areas. The third method is to ask the experts and develop a probability range around an estimate.[9]

The usefulness and accuracy of each of these methods is, of course, open to sharp attack, on the grounds that we cannot estimate a phenomenon when our basic scientific understanding of that phenomenon is flawed. At the beginning of the energy crisis, when it became very important to develop an understanding of the future availability of petroleum and natural gas in the United States for public policy purposes, the Federal Energy Administration asked a group of distinguished statisticians to look at the alternative methods for estimating the ultimate reserves or producibility of oil and gas in the United States. These statisticians, working independently, each arrived at the same conclusion that none of these estimating techniques was statistically reliable.[10] The U.S. Geological Survey has developed a model for the availability of petroleum that shows the absolute necessity of starting with a scientifically justified model of the occurrence of deposits by size distribution and other characteristics in the earth's crust. This has to be followed with knowledge of how many of these deposits can be discovered and at what cost through exploration, and so on through the development and production stage.[11]

The import of the preceding paragraph is that *we must give up any hope of developing a scientific model of future availability at what cost for any material or energy resource*. At best we can take the first element of resource classification, reserves, as the minimum that will become available, by definition, at current real price. Beyond that, we can—with decreased certainty—estimate geologic discoveries and technological advances. It must be understood, however, that any figure or range of figures so developed misstates the fundamental concept of the supply of resources. The supply of resources is, in fact, a flow of resources to the economy. It is not the exhaustion of a fixed stock. Whether or not resource depletion in the sense of rising costs occurs is a function of future technology in exploration and in production.

Knowledge of future supply side availability is very limited. The origin and real costs of supplies for the next decade are now known with very small margin of error. The margin of error consists primarily of the political availability of known resources, that is, cut-offs in supplies arising from political constraints, such as war or embargo. In addition, there is the unknown probability of major natural disasters. Finally, there is a small probability at the margin that major new deposits or technical advance could change the supply situation within the next decade. The latter is extremely unlikely, given the long lead times necessary to develop the productive capacity and infrastructure involved in major new material and energy projects. For many commodities, current reserves contain quantities that still will not be used before the end of the century. For others, current reserves will not last this decade if demand for them continues at current levels.

DEMAND SIDE OF ADEQUACY

The determinants of resource demand can be categorized into seven major variables:[12]

(1) Demographic variables such as size, rate of growth, and age and sex distribution of population; number of households; and labor-force participation rates.
(2) Standard of living, usually represented by per capita gross product.
(3) Style of living, such as the pattern of preferences in consumer goods and transportation services.
(4) Geographic distribution of population between urban and rural.
(5) Technological structure, that is, the means by which goods are produced from resources.
(6) International trade relationships.
(7) Institutions and policies, for example, environmental requirements.

The above factors affect the demand for total resources. The use of any single resource is the result of demands for final goods, the technology of production of each good, and relative prices.

It is clear that many of these variables are useless for projecting material demands, since their projection is difficult, and the relationship between them and specific resource demands is very complex and uncertain. Most analyses of projected resource demands rest upon some simple assumptions of the relationship among specific resource demand, levels of production, and, in some cases, the price of the resource. The important point to be made here is that, just like the supply side of adequacy, the demand side of adequacy is essentially unknown and unknowable, as it depends irrevocably upon the development of future technologies and price relationships.

RECENT STUDIES OF RESOURCE ADEQUACY

There have been three major studies, published in 1979 and 1980, which have attempted to measure in quantitative terms the adequacy of materials and fuels resources.[13] These studies carefully examine the evidence, make what the authors consider to be conservative projections, and draw general conclusions. All three studies indicate that depletion, as measured by its economic dimension of increasing costs, does not present a challenge to resource adequacy for a minimum of three decades. The studies do conclude, however, that in the area of energy, society faces a transition from its current sources to alternative sources, and that the effect of resource depletion on the quality of life rests upon the successful conduct of that transition.

The concept of resource adequacy rests upon the conjunction of materials and energy supply with materials and energy demand. The essential problem is whether quantities will be available at any given price level to meet requirements at that price level. The future characteristics of economic availability are unknown and, at the current state of knowledge, unknowable. Therefore, any projections of availability as a function of price through time for mineral resources are highly uncertain. The same can be said for the projection for the use of mineral resources, that is, the demand side. Both the supply function and the demand function are subject to extremely complex determination, and prediction of the factors determining each through the future is virtually impossible. The predictions progressively lose credibility as a function of future time. The situation is not, however, as bleak as it seems. If the adequacy of resource availability is seen as a process rather than a point estimation, it is possible to develop strategies addressed to the process itself which have implications and viabilities beyond our knowledge of future outcomes.

WORLDWIDE DISTRIBUTION OF RESERVES

Reserves are developed in response to economic incentives, that is, the prospects of returns from development of mineral resources. The factors that determine which deposits will be discovered and then developed into productive reserves involve calculations not only of the costs of developing the deposit itself but also of transportation and marketing of the output. The closer a given deposit is to the market place, the greater the likelihood it will be developed. Deposits in remote areas must carry a substantial premium in the sense of economic rents to justify the transportation and other costs involved in their development.

It is not surprising, then, that mineral developments have been located near industrial markets. The importance of location to production is perhaps best illustrated by the steel industry, where location has been the result of the confluence of the basic raw materials, energy, and markets. In the United States, the original centers of production were in the Pittsburgh area. These centers used river transportation for the coal, iron ore, limestone, and other inputs to the process, and served the emerging industrial complex of Pennsylvania and Ohio. As the iron ore supply shifted northward to Minnesota, a second complex, centered in Gary, Indiana, was generated along the shores of Lake Michigan. The Japanese steel industry takes full advantage of low-cost ocean transportation for all of its raw materials and much of its product. The total cost of supplying a market is critical in decisions about where to locate production.

Of course, the location decision is affected by the geology of the mineral resource itself. Given all other factors, however, exploration will tend to be concentrated in those areas where development would be relatively easy. An oil reservoir might be a bonanza in Oklahoma, for example; yet the same oil reservoir in offshore Nova Scotia might not be a commercial find.

Resources can be categorized with respect to the importance of the market and transportation systems in their location. For the construction materials that make up in total bulk most of the materials society uses, development is almost entirely market oriented. At the other extreme, the ferroalloy metals, which are geographically scarce and measured in pounds rather than in tons, are developed where they are found. Most major resources lie between these extremes.

Commodities produced far from their markets create international security implications. The major one, of course, is petroleum, but cobalt, chromium, platinum group metals, manganese, copper, and bauxite are also important. Each of these is briefly discussed below.

PETROLEUM

The United States and other Western industrialized countries use petroleum primarily for transportation, but also for industrial processing and household energy. The bulk of petroleum entering into world trade is subject to the actions of a cartel that has been successful in raising the price of petroleum in the world markets. The success of the cartel flows from two fundamental characteristics of the petroleum market:

- Because the demand for liquid petroleum is technologically fixed in its transportation uses, at least for a significant period of time, rapid substitution away from liquid petroleum in transportation is virtually impossible.
- The search for new petroleum reserves is expensive and carries a long lead time, and so the development of reserves outside of the cartel's control is a relatively slow process.

These two factors combined have permitted the cartel to raise the price of petroleum on world markets by an order of magnitude over the past ten years. The Arab portion of the OPEC cartel did use the "oil weapon" and imposed an embargo in 1973, and supply from the Middle East has been interrupted periodically due to wars since 1950. Thus, petroleum is an example of a concentration of world reserves under the control of a cartel and subject to supply interruption by deliberate action or as a result of political developments.

COBALT

Over 40 percent of the world mine production of cobalt comes from Zaire, which has well over a third of the world reserve base. Cobalt has a variety of uses, but its most important one, from the point of view of international security, is for turbine engines in aircraft. It is produced as a by-product of copper and the price is set by the Zairian source. Total world production is only about 35,000 tons.

CHROMIUM

Chromium is an essential ingredient for the making of stainless steel. Thirty-five percent of world production comes from the Republic of South Africa, which also has two-thirds of the world reserve base.

PLATINUM

Half of the world production and three-quarters of the world's reserve base for platinum group metals is in the Republic of South Africa. Virtually all of the remainder is in the Soviet Union. A major use of platinum that raises international security implications is its use as a catalyst in the refining of petroleum. It is also used for emission control in automobiles in the United States.

MANGANESE

Manganese is an essential ingredient, under current technology, for the making of steel. The Republic of South Africa supplies a fifth of the world's mine production, but over 40 percent of the free world production. South Africa contains three-quarters of the free world reserves and about a third of the world reserves of manganese.

COPPER

Copper reserves are much more broadly distributed than the other commodities listed above, but copper does not enter into world trade in significant volumes. The largest producers are the United States, Chile, the Soviet Union, Canada, and Zambia, in decreasing order. On the reserve base side, the reserves are held approximately one-fifth by Chile, another fifth by the United States, followed by Russia, Zambia, and Canada, each of whom has less than 10 percent.

BAUXITE

Bauxite is the ore for aluminum. Bauxite ores are widely distributed throughout the world, but bauxite is a commodity in which the geographical separation between the ore producers and the metal producers is pronounced and virtually all of the bauxite enters into foreign trade. The largest producer is Australia which accounts for about 30 percent of the world's production. Guinea and Jamaica each produce about 15 percent, and individual countries drop off sharply from that level. On the reserve side, Guinea has approximately 30 percent, Australia 20 percent, followed by Brazil and Jamaica with about 10 percent each.

SUMMARY

Distribution of reserves and productive capacity within the world arises from geologic and economic factors. As indicated above, geology has played the most important role in production of petroleum and some of the ferro-alloy metals. For most other materials the primary factor has been economics, not geology.

RESOURCES AND ECONOMIC DEVELOPMENT

Abundant natural resources have played a major role in the economic development of the nations of the world. At the time of the industrial revolution, the confluence of energy and material availability was a determining factor in the location of major industrial activities. Clearly, the emergence of Great Britain, Western Europe, the United States, and Japan as major industrial powers is based upon a natural endowment of energy and material resources or access to ocean transportation to permit their acquisition relatively cheaply.

The developing countries now look upon resources as a major means of facilitating their economic development. The export earnings flowing to the oil producers, greatly enlarged by their cartel action, have provided a clear example of the transfer of wealth from the industrialized countries to the raw material producers. In addition to petroleum, copper has played a major role in Chile and Zambia and is looked upon as a major contributor in such countries as Papua New Guinea and Panama. The Republic of South Africa, which is blessed geologically with a disproportionate endowment of manganese, chrome, and platinum group metals, has used these materials plus gold and diamonds as a major source of its wealth.

Among the industrialized countries, the Soviet Union is least dependent upon the international flow of goods for its mineral and energy supplies. In part, this is due to resource endowment, but it is also due to deliberate government policies. The Soviet Union, for example, does not rely on imports of bauxite for its aluminum and thereby imposes substantial additional costs for the production of aluminum metals. At the other extreme, Japan has virtually no natural resources and is therefore almost entirely dependent upon the rest of the world for imports of materials and energy for her industrial production. Between these extremes, the United States lies closer to Russia, and Europe lies closer to Japan.

The nonindustrialized areas of the world depend upon raw material exports as their major earner of claims to goods and services, and the industrialized countries depend upon raw material imports to maintain their economies. This fact creates, in essence, a bilateral monopoly bargaining position between the raw material exporters and the industrialized countries of the West. The exporters have a strong bargaining chip in that the industrialized societies, certainly within short time spans, cannot operate without the materials and energy they produce. On the other hand, unless these materials and energy are sold to the industrialized countries, the exporters will not be able to enjoy the returns from them and will suffer dramatically in terms of wealth.

ROLE OF DEPLETION

The time frame of this paper is five years or, generously, the decade of the 1980s. Depletion of materials and energy resources during the next ten years will not significantly affect the flows of trade and the international security aspects of materials and energy availability to the United States. In this sense, depletion is simply unimportant within the context of this analysis.

In two of the specific commodities we have already discussed, however, historical depletion is important to the current situation. The United States was the first large developer and user of petroleum in the world and has for many years maintained a position as either the major or a major producer of copper. On a relative basis then, the geologic deposits of petroleum and copper available within the continental United States have been depleted relative to deposits occurring in other portions of the world. To the extent that intensive exploration for these resources has discovered relatively high grade and easily found resources within the land available for exploitation, future discoveries will be relatively less probable in the United States than in the rest of the world. The same situation applies to a wide range of other materials found in the United States, such as zinc, potash, and sulfur.

For the other materials discussed above, however, geological factors have prevented the United States from ever enjoying comparative advantage in their production. These materials are relatively scarce ones (except bauxite) and the best deposits simply do not occur within the boundaries of this country. Thus, the development of these materials has occurred outside of the United States and depletion, as such, has played no role in that development.

From a world perspective, issues of resource depletion may have implications centuries from now. Much fundamental work is now being undertaken to try to understand the nature of substitution between resources, capital, and labor in the production function of society.[14] If, in fact, this substitution is limited, then the question of resource constraints placing a major limit on the growth and welfare of society is perhaps still open. Depletion in this sense is of great theoretical interest, but of little practical interest in terms of resource availability over the next ten years.

INTERNATIONAL SECURITY ISSUES

Two major issues arise from the geographic and economic distribution of materials and energy raw materials in the world:

(1) How can the industrialized world deal with supply interruptions?

(2) Does relative depletion of resources in the industrialized countries jeopardize the comparative advantage of the manufacturing sectors of these economies, leading to short-term transition problems and long-term deterioration in their terms of trade?

The United States has been addressing the first issue in several contexts almost continuously since World War II. A large number of presidential commissions and special studies have dealt with the so-called critical materials problem. At present, for example, serious discussions concerning the "resource war" with southern Africa label the Republic of South Africa in particular as the "Saudi Arabia" of materials.[15] In the United States, the President's nonfuel mineral policy study draft report identifies the concentration of productive capacity and reserves in southern Africa of chromium, cobalt, manganese, and the platinum group metals as a major issue with respect to short-term interruption of supplies.[16] The so-called energy crisis is precisely of the same nature, in that interruptions of petroleum have immediate and serious consequences to the industrialized countries.

A second consideration, separate but related to supply interruptions, is the economic terms upon which these internationally traded materials become available to industrialized societies. Oil is the significant material that raises this issue, simply because of its importance in the world economy. Cartels have been tried in bauxite, and there is producer pricing of both cobalt and chrome. These materials have economic values in the small range of millions of dollars, however, rather than in the tens of billions, and thus the impact of price rises on the overall economy is relatively trivial.

The issue of loss of comparative advantage is a serious one for the future of the United States, in particular. The U.S. industrial base was built while the United States had access to cheap and conveniently placed natural resources. Several basic industries are showing signs that they have lost their international comparative advantage and perhaps their absolute advantage. The problems of the steel industry, the automobile industry, and the textile industry are symptomatic of this development. So long as the decline occurs in an orderly way and does not generate substantial local income distribution problems, its impact may not raise serious issues. But in the case of steel and automobiles, in particular, the transfer of labor and capital from a declining basic industry to a growing sector of the economy generates very substantial economic problems and perhaps international security implications.

The two problems are related and aggravated, in part, by relative resource depletion. Such relative depletion contributes to the loss of comparative advantage, which in turn contributes to increasing import flows of basic commodities, such as steel.

ALTERNATIVE STRATEGIES

The issues of supply interruption and loss of comparative international advantage are interrelated in a direct but subtle way. If society decides to solve the first problem in ways that substantially increase the cost of raw material supplies, it will exacerbate the second problem of comparative advantage. Energy provides a clear example. The industries suffering a loss of comparative advantage, such as the primary metals and basic manufacturing industries, have energy as a major cost of production. Thus, if the United States decides to solve its energy supply problem by imposing substantial costs on U.S. consumers above those borne by the other industrialized countries, this action in and of itself will accelerate the problems arising from a declining industrial base. This implies that the strategies for attacking these two problems must be considered together. Any viable solution must take full account of their interdependence.

THE SELF-SUFFICIENCY STRATEGY

This is presented in the hopes that it will be perceived as a straw man argument. It must be taken somewhat seriously, however, since the initial response of the federal government to the Arab oil embargo of 1973 was to proclaim a drive for "energy independence." It also gains credence in the increasing references from many sources to the fact that the Soviet Union is virtually self-sufficient in energy and materials and this is held out as a major threat to United States economic and national security.[17]

The implications of the strategy are immense. First, it would involve the cut-off of the United States from its export markets and from efficient and cheap imports. This would reduce the productivity of the United States economy and move the economy toward a prolonged period of slow growth or stagnation. Second, it would isolate the United States politically from its allies and create very serious problems in national defense. Third, it would isolate the United States from the emerging Third World and ultimately exacerbate serious political and security problems. This is not the place to fully detail the implications of self-sufficiency and the reemergence of autarchy in the world, but it is clear that the severity of the national security issues identified here argue against the sledgehammer solution of imposed self-sufficiency. Self-sufficiency as a strategy, of course, would address both of the issues identified above.

STRATEGIES FOR SUPPLY INTERRUPTION

There are in general several approaches to lessen the impact of a supply interruption on those materials for which the United States depends significantly on foreign sources, including:

- maintenance of stocks of the material within the continental United States;
- maintenance of standby productive capacity for the material in the United States;
- development of on-the-shelf technology to substitute for the specific material in critical uses;
- fostering design changes to minimize the use of the material;
- creating substitutes for the imported material from domestic production of the same material on a subsidized basis.

Any of these strategies involve a cost to society justified, presumably, by the benefit in mitigating the probability of a costly supply interruption. The strategy which should be followed depends then on the specific commodity situation with which the United States is faced. We have already decided in the case of materials needed for national defense that a strategic stockpile of supplies for a specific national security emergency is the best form of insurance. That strategic stockpile, however, is not useful for commercial supply interruptions and may involve substantial costs to society because it must be maintained for use in a national security crisis.

The alternative solutions to the problem of supply interruption all involve scientific and technological components. A deep-sea mining capability, for example, would immediately change the reserve and production picture for copper, nickel, cobalt, and manganese, and might make the United States an exporter rather than an importer of these materials. Deep-sea mining might have benefits out-weighing its economic costs, and therefore justify a security premium or subsidy to speed its development. Similarly, if research could yield a substitute for cobalt, based upon a more abundant material, the security premium involved in cobalt could justify our investment in the technology required to produce the substitute.

The policy issues raised by these alternatives are to a great extent specific to a given commodity, and must be considered on a case by case basis. Much of the analysis which has been done in the critical materials area indicates that an effective and carefully drawn stockpile proposal is, in many cases, the cost-efficient insurance against supply interruptions. Other of the above policies, however, may be the cost-efficient approach in some cases. It is clear that the incentives for private research and the development of new production strategies and substitutes do not reflect society's costs in dependence upon foreign sources which can be interrupted for political purposes. Thus, there is a prima facie case that research into developing the alternatives other than stockpiling indicated above should be properly undertaken at the expense of the society as a whole rather than the private sector alone.

This leads, then, to two recommendations concerning strategies for dealing with the issue of supply interruptions. The first is that for the selected materials upon which the United States is dependent on overseas sources, a strategy be established for each material to achieve protection from supply interruption in the most cost-efficient manner given the current state of technology in production and use. Second, additional support should be undertaken for basic research in innovative technologies for continuing to produce existing materials and for creating new resource substitutes. This would be long-term strategy for decreasing the cost of insurance against supply interruption.

STRATEGIES FOR THE LOSS OF COMPARATIVE ADVANTAGE

This issue raises policy questions which run well beyond the availability of raw materials. It includes issues of productivity, industrial management, tax policy, and even the rate of savings in the U.S. economy. The fundamental attack on this issue must be in research and innovation to substantially reduce the real costs of producing the primary minerals and the basic industrial products at home. This can be achieved by research aimed (1) at the production technologies themselves, and (2) at producing a substitute for the basic material and manufacturing outputs at substantially lowered costs.

It has been demonstrated that because of a basic market failure, research and development are not pursued at a socially optimal level in the United States.[18] Thus, we need to expand the level of research and development to attack the fundamental issue of the overall productivity of our industrial base. This is the third recommendation.

THE NEED FOR BETTER KNOWLEDGE

We are fundamentally ignorant about the geological deposition of mineral and energy deposits in the earth's crust. The determinants of the level and the efficiency of the exploration process are not known. There is much to be learned about ways in which changes in certain institutional structures, such as nationalized firms, countries operating as entrepreneurs, and multinational multiproduct private corporations, affect the flow of mineral supplies. The same state of ignorance exists on the demand side of trade in resources.

The major presidential commissions that have reported on materials problems, including the draft report of the recent presidential study, all have called for increased attention to the data and analytical information available to policymakers in both the government and the private sector. The fourth recommendation of this paper is the establishment of improved data and analytical capabilities in the federal government, including substantial research in the basic geological and social sciences directed at the mineral and energy resources sectors.

SUMMARY

The role of depletion in international security affairs flows primarily from the relative depletion of resources in the United States; this depletion has meant substantial change in comparative advantage for both the minerals and resources industries and for the primary industrial sectors that are based upon them. Along with geologic endowment, this situation leads to a dependence upon foreign sources for certain materials. Supply of these materials is thus subject to political interruption and to a major problem in transition from previously efficient industries to newly emerging growth sectors in the economy.

To deal with these issues in their resource and energy context, four recommendations are made:

(1) Establish, for each material upon which the United States is dependent on overseas sources, a strategy for achieving protection from supply interruption in the most cost-efficient manner, given the current state of technology in production and use.
(2) Undertake additional support for basic research in new production technologies for these materials and in the development of substitutes for them, as a long-term strategy for decreasing the cost of insurance against supply interruption.
(3) Expand the level of basic research and development to counteract the declining productivity of our industrial base.
(4) Improve the data and analytical system for materials and energy, as a guide to both the federal government and private industry.

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11 Science and National Defense: A Speculative Essay and Discussion

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INTRODUCTION

This is an unusual paper which does not conform to the general pattern of the papers in this series because it deals with an almost unprecedented problem. Most of the papers deal, quite legitimately, with research priorities within an existing framework of ideas. They are within the setting, that is, of what Thomas Kuhn calls "normal science." What I am proposing is a basic parametric change in our whole view of the problem, that is, a scientific revolution. I am not asking myself what is the best thing to do within the existing framework; I am asking, is the existing framework adequate, and coming out with the answer that it is not. A profound change in our whole way of thinking about national defense is necessary. Another paper could easily be written along the lines of "normal science" within the existing framework. Someone else would have to be found to do it.

This paper, like the others, was discussed among five colleagues at the AAAS workshop on "Science, Technology, and International Security": Dr. Wayne Bert, Dr. Davis Bobrow, Dr. John Coleman, Dr. Richard Scribner, and Dr. Lorin Stieff. I found both their written reviews and the exciting oral discussion that we had extremely helpful. What I hoped that my original paper would do was not to solve the problems, but to start a discussion and to raise questions. This I feel it did among the discussants. Rather than prepare a new version of the paper, therefore, because the discussion itself is what the paper was intended to provoke, I am presenting a somewhat shortened and revised version of the original paper, in the light of some textual criticisms, without changing its essential content. Then I am presenting a summary of the discussion and my response to it.

SCIENCE AND NATIONAL DEFENSE

It is the business of the scientific community to perceive and to transmit into human consciousness testable images of the orderly patterns of the real world. It is the business of a science-based technology to utilize the perceptions of science to transform the real world in directions which are favorable to at least somebody's human valuations, that is, directions which in some sense are "better" rather than "worse." The orderly patterns of the real world cover systems of a wide range of complexity and structure, from the relatively simple patterns of the physical world to the greatest complexity of which we are aware, human beings and their societies.

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National defense is primarily a subset of the social system insofar as it is concerned with human beings and with their technological artifacts. It also has relationships with the biological and physical sciences. Certainly the development of chemical, biological and especially nuclear weapons has had a profound impact on it. Nevertheless, it remains essentially a part of the social system; it cannot be understood except in relation to social systems. The physical and biological sciences affect the parameters of social systems but do not in themselves explain them.

Within the general pattern of the world social system, national defense deals with certain aspects of the organization and interaction of national states. National defense is a subset of the "threat system." The threat system is part of the social system in which human behavior is organized by threats rather than by exchange or by integrative structures. Because society is an ecosystem, however, all these things are related. National defense organizations, such as armed forces and departments of defense, operate in part within an exchange system in that they buy and sell things. Their capacity for survival also depends very much on the general structure of legitimacy, which is an aspect of the integrative structure. No organization can survive in a society if it is widely perceived as illegitimate, especially by those who participate in it. All national defense organizations are financed by government appropriations of money, which in turn are obtained through tax systems or through the creation of money by the state. These political structures, again, rest on what might be called legitimated threat, which again tends to break down if it is not widely felt to be legitimate.

The dynamics of legitimacy are very complex, yet are also highly relevant to the problem of national defense. Legitimacy seems to come from two quite different and contradictory sources, which explains, perhaps, why it produces systems exhibiting great discontinuities. Ancient legitimacies which have persisted unchanged for a very long time sometimes collapse overnight. One important source of legitimacy is positive payoffs. Something which is perceived as clearly beneficial would tend to acquire and to retain legitimacy. The love of country, like the love of spouse, is certainly not unrelated to our perception of net benefits received from the association. Institutions that are perceived as no longer paying off and as yielding small or negative benefits are apt to lose legitimacy, as absolute monarchy did in the eighteenth century and empire did in the twentieth century.

This, however, is not enough to explain the complex dynamics of legitimacy. We also have a strange phenomenon that I call the "sacrifice trap." Negative payoffs also produce legitimacy, simply because suffering creates a sense of identity that is extremely painful to deny. If we have made sacrifices for anything, our identity becomes bound up with the objects and the purposes of those sacrifices and it becomes extremely hard for us to admit that our sacrifices have been in vain. Unhappy marriages sometimes last longer than happy marriages. The blood of the martyrs is the seed of the church; the blood of the soldiers is the seed of the national state. Sacrifices, and the demand for sacrifice, often tend to grow until at some point they reach a discontinuity and the whole system collapses. The history of revolutions and reformations amply testifies to this.

The persistence of threat systems in human history, in spite of the fact that they probably have a very low overall payoff in terms of human welfare, has a lot to do with the curious combination of positive and negative payoffs which they involve. A threat system essentially begins with a statement on the part of the threatener to the effect, "You do something that I want, or I'll do something that you don't want." The subsequent system depends on the response of the threatened. There are at least four possible responses. The first response is submission, in which case the threat is not carried out, but the threatened party makes sacrifices and the threatener presumably benefits. Secondly, there is defiance, in which the threatened party refuses to do what the threatener wants. This moves the system back to the threatener, who then has to decide whether or not to carry out the threat. If he carries out the threat, both parties are injured. Carrying out a threat involves costs on the part of the threatener as well as damage to the threatened. If the threatener does not carry out his threat, his credibility may be impaired, so there is again the cost to the threatener. The decision obviously depends to some extent on the evaluation of these different costs when compared to the probable value of the benefits derived from the chance of submission of the threatened party.

A third possible response to threat is flight, which has been very common in human history, from the Israelites in Egypt to refugees everywhere. A fourth response is counterthreat, in which the threatened party responds by saying, "If you do something nasty to me, I'll do something nasty to you." If this results in neither threat being carried out, we have deterrence. Deterrence, however, is always subject to breakdown. It puts stress on both parties and tends to produce escalation of threat. An arms race, in which each party in the attempt to stabilize deterrence increases his threat capability, is an example. This then creates a corresponding threat increase on the part of others that may or may not reach some sort of equilibrium. Usually it does not, and systems of deterrence, while they are frequently stable in the short run, are rarely, if ever, stable in the long run. Indeed, we can argue that deterrence cannot be stable in the long run, for if it were stable it would cease to deter.

The institutions of national defense are the result of a long evolution of threat systems that is still continuing.

In the neolithic, threat systems seemed to diminish in importance as opportunities for agricultural expansion increased. The rise of cities, however, in early civilization, some 3000 B.C. or a little earlier, was clearly related to the development of organized threat systems in the shape of armies and of tax-gathering bureaucracies headed by kings, although the earliest cities seem to have been theocracies, and were organized perhaps by the spiritual threats of a priesthood.

A fundamental principle of threat systems is that the size of both the area and the population that can be organized into a single system by threat is a function of the range of the instruments of threat, particularly, of course, of weapons. Obviously these are by no means the only instruments. Ancient empires depended in considerable measure on the development of mobile armies, like those of Assyria or of Alexander, which were indeed the first "guided missiles." A critical factor here is what I have elsewhere called the "loss of strength gradient."[1] The principle is that the farther one is from home, the less influence one can exert. This principle expresses itself in the exchange system in terms of the cost of transporting goods and in the threat system in terms of the cost of transporting "bads." The diminution of this gradient, through a fall in the unit cost of transport, permits the development of larger organizations.

Another factor in the situation is the relationship between the development of instruments of threat, that is, capability of doing harm, and instruments of protection, which would prevent harm being done. Spears, arrows, guns, and nuclear missiles are instruments of threat. Shields, armor, walls, and bomb shelters are instruments of protection, which diminish the effects of the instruments of threat. Throughout human history there seems to be a constant seesaw between these two groups of instruments. The rise of technological instruments of threat expands the area of threat-based organizations; a rise in the capacity of instruments of protection can diminish it. As armies produced empires, walls produced city-states and feudal barons. Both instruments of threat and instruments of protection, however, are costly to the users, and their relative costs are very important.

One of the curious consequences of the rise of science seems to be that it has accelerated the development of instruments of threat more than the development of instruments of protection. We see evidence of this even in what might be called the eoscientific era of the late Middle Ages with the development of gunpowder, which improved the range of instruments of threat so considerably that the feudal castle was no longer a viable defense system. The feudal system collapsed and was replaced by the much larger national state, the boundaries of which could be defended, at least in the short run, by mobile armies. The European empires from the fifteenth century on were largely a result of the extraordinary cheapness of sea transport, available once a certain level of technology had been reached. In earlier times, this played an important role in developing the Roman Empire, though land transport by Roman roads also helped. The Spanish, Portuguese, later the British, French and Dutch empires, were temporary products of this seapower technology. Mahan[2] pointed out that the American Revolution probably was successful because, for a brief period, the British lost command of the seas to the French.

Organized science played rather a minor role in this development, which mainly was due to improvements in what might be called "folk technology," especially in seafaring. However, science did play an important role in the improvement of maps and charts, and in the development of the skills of navigation, as it had done many centuries earlier in the observations of latitude, and in the eighteenth century in the solution of the problem of longitude. Even the development of steam engines and railroads does not owe very much to organized science. As has been said, thermodynamics owed a great deal to the steam engine, but the steam engine owed very little to thermodynamics. The great explosion of science-based technology began about 1860 with the development of the chemical and electrical industries, scientific metallurgy and agriculture. In the twentieth century, it continued with the nuclear industry.

This upsurge of science-based technology had an enormous impact on the technology of weaponry, especially on the range and destructiveness of weapons and their divorce from human operations. This has had a profound though confusing effect on the structure of national defense. In an age when, for the first time in human history a unified world state has become technologically feasible, we have seen the collapse of empires and a great proliferation of independent national states, the number of which has almost trebled in the last 30 years. Nuclear deterrence has been stable now since Hiroshima and Nagasaki, for there have been no further explosions (in war) of nuclear weapons. But there is an overwhelming fear that this stability may not last, and that we are indeed sliding at an accelerating pace down a slippery slope towards a potentially irretrievable nuclear catastrophe.

The brutal truth is that a science-based technology has made the unilateral national defense of the national state ultimately a non-viable system. As long as the nuclear weapons exist, the probability of their being used is not zero. No matter how low the probability of any event, if we wait long enough, it will come off. My own highly subjective estimate is that over the last 30 years or so the probability of nuclear war has been of the same order of magnitude as that of a 100-year flood, about one percent or less per annum. I suspect that it rose to something like 20 percent in the Cuban crisis and is edging upwards to two, three, four, maybe five percent per annum today. These, of course, are subjective evaluations, unfortunately incapable of being tested directly and, therefore, not strictly scientific. But a lot of things that are not scientific may turn out to be true.

All this evidence suggests that we are in a very strange situation, and that we are moving toward highly unfamiliar regions of the system. The collapse of the old empires, the powerlessness of the superpowers, and the many signs of the widespread erosion of the legitimacy of war as a system, indicate that we may be approaching a moment of profound evolutionary change. The impotence of the superpowers was certainly seen in the case of the United States in Vietnam, and in the constant frustrations of the Soviet Union in its attempts to operate in various parts of the world, such as in Egypt and now in Poland. It will be surprising if the Soviet Union does not find itself confronted with the same kind of bleeding abscess in Afghanistan that the United States found itself with in Vietnam. In Cuba, Angola, and Ethiopia, the Russians find themselves with never-ending costs of support, from which it is very difficult to see that they receive the slightest benefit. As the British, the French, and the Dutch found, being an imperial power does not pay. These countries have all done much better economically since they shucked off their empires. It is also likely that being a superpower does not pay, though it is taking us some time to discover this.

All this philosophy is reflected in the continual erosion of what might be called the military ethic and culture. This is reflected, for instance, in war songs. The First World War produced a fine crop, the Second World War produced none, and the Vietnam War produced nothing but anti-war songs. The tradition of military sacrifice, which goes back a very long way in human history, could be on the point of collapse. When the sacrifice involves hundreds of millions of civilians, and the military activity consists of pressing a button in a safe shelter, the end victory does not seem worthwhile.

The loss of an old legitimacy, however, can be very dangerous if it is not replaced by another, and at the moment, certainly neither war nor peace seem to be legitimate. If the 1980 election is any indication, the American people still seem to believe that a military defense will give them security, in spite of a great deal of evidence to the contrary. The scientific community has a responsibility in this matter because it has played a highly significant role in creating the technical change in weaponry which has destroyed the unconditional viability even of the largest national state, just as much as gunpowder destroyed the viability of the feudal baron. Neither deterrence nor bomb shelters can save us in the long run. The technology of protection is fundamentally helpless in the face of the technology of destruction. A society living in bomb shelters is not worth living in, quite apart from the difficulty it would have in raising its food supply! Present-day technology offers no solution to the problem of civil defense, and only the Chinese seem to have any illusions about its feasibility. The civilian populations of the developed world are hostages to their departments of defense. They are not really defended by them. This is a condition for which the scientific community bears an inescapable responsibility because it has assisted in the production of the technology which has created it.

Does, then, the scientific community have resources within it which can answer the accusation that it has contributed to the probability of destruction of the human race as well as to its betterment? The answer to that question is perhaps a somewhat hesitant "yes." In the first place, the scientific community is a product of a very remarkable ethos, the origins of which are somewhat obscure, which attaches great value to the principle that people should be persuaded by evidence and not by threat. This renunciation of threat by the scientific community was a very important element in its remarkable success at expanding human knowledge. The principle that the real world should speak for itself through testing and through the evidence presented by tests was something new in the experience of the human race. All previous societies relied upon threat to insure conformity of belief and practice. It is surprising how little understanding there is of this basic principle even within the scientific community, for it is practiced widely, although with occasional exceptions at the personal level. For example, in graduate schools, the unusually imaginative and creative graduate student who disagrees with the views of his professors may find himself subject to a threat system when it comes to his final examinations. This, however, is an exception, and on the whole, the renunciation of threat, particularly among peers, is perhaps the basic ethical commitment of the scientific community. If a scientist cannot persuade his peers of the truth of his views by the evidence presented, he has no other recourse.

It is to my mind a gross violation of the scientific ethic to do what the Soviet Union did in its relations with China after 1960 and what the United States is now doing in regard to its relations with the Soviet Union. Both countries are using science as part of the political threat system by withdrawing scientific contacts and communication. It is to the great credit of the Soviet scientific community that it produced a Sakharov. It is no credit at all to the American scientific community that it does not seem to have produced one. Nevertheless, the scientific community has a large reserve of what might be called the "moral resource." In social systems this resource is just as important and just as real as natural resources.

The scientific community, however, has more than this. In the last 30 years or so there has developed a considerable literature and something that could properly be called a discipline in a field which is so new that even its name has not been firmly established. I like to call it "conflict studies." The French call it "polemologie." It has gotten to the point where at least 80 colleges offer something like an interdisciplinary program in it for undergraduates. Conflict studies is still very precariously established at the graduate level, though there are a number of institutions around the world that do offer a graduate program in it. In its applied form it sometimes goes by the name of peace research or peace science, but in its more pure form it transcends the political and ethical distinction between hawks and doves. In its applied form it goes well beyond the problem of international conflict and makes contributions indeed to such things as arbitration, conciliation, and mediation in commercial and labor disputes and community conflict. The existence of the discipline is at least partially acknowledged in the congressional commission set up in 1980 to study the formation of a National Academy of Peace and Conflict Resolution. If such an academy comes into being, it will, of course, be a public recognition of the existence of the new discipline.

The new discipline comes out of all the older social sciences. Historically, it owes a great deal to the work of political scientist and historian Quincy Wright and to meteorologist Lewis F. Richardson.[3] The discipline which it perhaps most closely resembles is economics, for just as economics abstracts from the complexity of social life the phenomenon of exchange and related topics and inquires how exchange organizes society, conflict studies abstracts the phenomenon of conflict, which again is virtually universal in all social relationships, and studies how this organizes society. Just as economics has had an important effect on public policy—not all of it necessarily benign—over the last 200 years, from free trade to fiscal and monetary policy, so conflict studies might be expected to have substantial effect on the way conflict is conducted in order to lower the costs of conflict to all parties. Conflict processes are strongly susceptible to what might be called "perverse dynamics," that is, processes in which rational decisions on the part of each party in fact make each party worse off. The famous theoretical treatment of this is the "prisoner's dilemma" of game theory, which has received a great deal of study in recent years. To those who are familiar with it, the theory can hardly help but make a difference in the way they behave in conflict situations.

Looking now at possible contributions over the next five years, perhaps the most optimistic scenario of the present conflict environment would be like that with the Soviet Union in the Cuban crisis, in which we will move towards the cliff of nuclear war and then turn back from it. This should arouse interest in the scientific study of conflict systems, but more particularly, it should arouse interest on the applied side in the study of the management of threat systems, which is something that has been greatly neglected, even in conflict studies. First, there is a great need for careful historical analysis of threat systems of the past and the way they have been managed. There is need for a much better information system to assess the consequences of threats, and even the description of them.

One of the great problems with the threat system is that its information processes and feedbacks are extremely poor even in comparison to the processes and feedbacks of the exchange system. In exchange we usually know fairly well what the exchange opportunities are which are open to us; thousands of prices are quoted daily in the press. The consequences of exchange are always somewhat uncertain, and exchange not infrequently results in disappointments, from which, however, we often learn rather rapidly. Once we have bought one lemon, we tend not to buy at least the same one again. In threat systems, however, the actual nature of the threats which are made are extremely uncertain and the consequences of making them are even less certain. Threat may convey one image to the threatener and a completely different image to the threatened, of which the threatener is not aware. Under these circumstances, it is not surprising that threat systems exhibit such striking pathologies and cause an enormous amount of human misery. An improved information system with regard to threats is surely possible, even though it is by no means easy. Just as we have substantially improved the information system in economics over the last 50 years, with the development of national income statistics and indices of various kinds, we can improve the information system in threat study.

The study of weapons systems and their development has grossly neglected the place of weapons in the general threat system. The study has also overlooked the fact that a weapon is not merely a physical system but that it is also part of the social system. In physical terms, we have overkill in table knives. We certainly have enough table knives to kill everybody in the world if they fitted into a social system which demanded it, but a table knife only becomes a weapon on very rare occasions. It is at least a plausible hypothesis that we have now gotten to the point where every improvement in weaponry lessens our security and lowers our chance for survival. How to test this hypothesis without waiting for our destruction is a difficult question. However, it is not an unworthy question for scientists to ask.

As we look at possible futures, some scenarios offer hope. One is the development of general and complete disarmament through a world state. This might come about either by a strengthening of the United Nations, which seems improbable at the moment, or by what seems even more improbable— the conquest of the world by a single country. Neither of these possibilities seems very hopeful. There is, however, another alternative, which is less drastic but more realistic—the development of expanding regions of stable peace. Stable peace is a phenomenon which was virtually unknown before the nineteenth century. After 1815, however, it developed in Scandinavia, and after perhaps 1870, it developed in North America. I think we can say it has now expanded to include Western Europe and Japan. We could almost think of a broad triangle of the globe with apices at Japan, Australia, and Sweden that is in the phase of stable peace. This phase of the international system involves first taking national frontiers off all agendas, except for mutually agreed adjustments. This leads to disarmed frontiers and national images which are consistent with each other. The probability of war between the constituent nations then becomes so small that it really does not enter into anybody's calculations. Stable peace is not the same as an alliance. Indeed, alliances against a common enemy do not produce stable peace, for both alliances and enmities shift. The allies of today become the enemies of tomorrow. This is not to deny that a common threat somewhere in the background may be a factor moving a group of nations into stable peace, but it is never the dominant factor.

The potentiality for stable peace unquestionably comes out of the extraordinary increase in productivity that has resulted from science-based technology. This technology has enormously diminished the comparative advantage of the threat system as a source of wealth when compared to productivity and exchange. In a technologically stagnant society like the Roman Empire, the economic gains of the threat system through conquest and plunder may have seemed attractive in the absence of any technological development. In the last 150 or 200 years, however, it has become very clear that with the effort and the cost required to extract one dollar from an exploited human being through the threat system, one could extract $50 out of nature. The rise of the rich countries to wealth in the last 150 years has not primarily been the result of exploiting the poor, but of the previously poor increasing their own productivity. Without this, it may well be that the conditions for stable peace might not have been developed. However, just because the underlying conditions exist does not necessarily mean that the international system itself will move toward stable peace. This requires either a set of lucky accidents, which I think was the case in North America, or perhaps in the future, a conscious and deliberate policy directed toward producing it.

The question as to whether a research program could be set up in this area obviously depends on whether people perceive this phenomenon as belonging to the real world or whether they think that a continuation of the present system of unstable peace is inevitable and unchangeable. It is difficult indeed for people to acknowledge that an institution like unilateral national defense, which is so ancient and so well established, is in fact coming to an end because of technical change. Even if the bulk of the scientific community is not willing to acknowledge this, there still may be support for a potential alternative. A program of research along these lines, therefore, is by no means utopian. It would involve theoretical, experimental, and historical research. A great deal needs to be done on the theory of threat systems. Something could be done through experimental social psychology. I confess I am personally a little skeptical about the payoffs there, but it would be worth trying. Principally, I would argue that the empirical research here has to be historical. A large-scale study of the history of threat systems, with the testing of a group of theoretical hypotheses in mind, would, it seems to me, pay off very substantially. If indeed the National Academy of Peace and Conflict Resolution is established, I would suggest that this should be its major priority.

SUMMARY OF THE DISCUSSION

Even though we did not use the term "scientific revolution," all the discussants agreed that what I am proposing is a very basic change in the parameters of the system of national defense. They agreed it was legitimate to raise this question and that the hypothesis was at least plausible that such a parametric change was in order, in view of my contention that technological change, particularly the enormous increase in the range and destructiveness of the guided missile, had made conventional unilateral national defense unworkable in the long run.

The discussants also felt, however, and I agreed with them, that I had not dealt with the shorter-run problems, particularly with the problem of transition from the existing system into one that was ultimately more viable. Dr. Wayne Bert made the point, for instance, that people in positions of political power in almost all nations do, in fact, feel threatened by the unilateral national defense establishments. In other words, they fear the armed forces and the political apparatus for deciding to use them which exist in other countries. The only response they can think of to this threat is to set up a unilateral national defense organization of their own, perhaps as a counterthreat. Nobody actually brought up the old Roman slogan, "*Si vis pacem pare bellum.*" (If you wish for peace, prepare for war.) But it is clear that much of the motivation which creates unilateral national defense organizations and which persuades scientists and many people of good will to go into them and support them is an ineradicable fear that their nation or society will be invaded, humiliated, or even destroyed by the unilateral national organizations of others, unless they have one of their own large enough to operate as a counterthreat.

The historical fact that preparing for war has very rarely, if ever, insured peace—Sweden in the last 300 years is about the only example that I can think of that is even plausible—either fails to rise into consciousness, or the fact that the price of unilateral national defense is occasional war is simply accepted as a cost which is worth the benefits derived from continued national existence and integrity. Before the development of the long-range nuclear missile, indeed, the above position was a very plausible interpretation of the condition of the world. This is not the first time in human history, however, that technical change has made a previous social orientation unviable. As I mentioned earlier in this paper, the impact of efficient cannon on the feudal system is a case in point. The scientific revolution and science-based technology destroyed both the economic and the political viability of slavery, although it took a long time to get the slave societies to recognize this. However, the question raised by Dr. Bert is a crucial one. It would involve a program of research in the field of transformation of human images of fact and value under pressure from the "real world," which at the moment we are poorly equipped to perform, but which is by no means beyond the capacity of the social science community.

Dr. Davis Bobrow raised some extremely penetrating questions, which also came up in the discussion, as to how the future of national defense related to the other topics of the symposium, particularly to the problems of population, resource exhaustion, and distribution of world development that were treated in other papers. There is a very important field of inquiry here. If we think of the international system as a system of "stress and strength," we can compare it to a complex network of rods, that occasionally "break" into war. If the strength of the system is greater than the stress on it, the rods do not break and there is peace. When the stress is greater than the strength, the rods break and there is war. The term "national strength" is often actually a factor in the stress that is placed on the system rather than a strength of it. An increase in national strength often increases the stress on the system.

Then the question arises, what do other large dynamic systems of population, resource exhaustion, economic development, and so on, do to the real strength of the world defense systems, or to the stresses on them? Will differential population growth, increasing poverty, and exhaustion of resources increase the stress? Do multinational corporations increase the strength of the system in the sense that they are profoundly interested in the maintenance of peace? Things like cultural exchange, scientific cooperation, and even tourism, may increase the strength of the system. The measurement problems here are extremely difficult. Nevertheless, the concepts are fairly clear, and one could certainly visualize a research program directed toward the impact of all the various facets of social dynamics on the overall strength and strain of the international system. This has rarely, if ever, been done.

Dr. Bobrow also suggested that useful work could be done with regard to a conceptual framework, which I had some hand in originating, but which was not mentioned in the paper. This deals with the various "phase descriptions" of the international system and the circumstances which move the system from one phase into another. In two previous works[4] I outline four possible phases of the international system. The first is "stable war," which actually is not too common in human history but is by no means unknown. The second is "unstable war," in which war is regarded as the norm but is interrupted by periods of peace, brought about by treaties, royal marriages, and the like. As the intervals of peace become longer, this phase passes, often imperceptibly with no very clear boundary, into a third phase of "unstable peace," in which peace is regarded as the norm but is interrupted by periods of war. The ostensible object of this phase is to restore peace, of course on terms favorable to the victor. And then, as I argue in the paper, since 1815 at least in some areas this has passed over into areas of "stable peace," in which the probability of war is extremely low, even between independent states.

Dr. Bobrow argues that in any appraisal of research and development, particularly technological development, in weaponry, for instance, the question of whether the change may shift the system from one phase to a more adverse phase should constantly be raised. I would go even further and suggest that in a sense these phases are related to the stress-strength model. In stable war the strength of the system is virtually zero; any stress results in war. As we move from unstable war into unstable peace, the strength of the system, relative to the stress, increases. As we move into stable peace, the strength of the system becomes so great that the stress never rises to the point where the system breaks. The research problem here actually has curious parallels to the problems involved in non-destructive testing. A system break is destructive testing of the relative stress and strength of the system. When the system is broken, we know that the stress is greater than the strength. Any increase in non-destructive testing would presumably create feedback systems which would lessen the possibility of destructive testing. The information and measurement problems here are very severe, but this should be a challenge to the scientific community to vigorously pursue the enterprise rather than to abandon it.

Dr. Bobrow raises the very important short-run question of whether the development of first-strike capability in either the United States or the Soviet Union, or both, lessens the strength of the system, makes catastrophic war more probable, diminishes our security, and moves us from the not-too-unstable peace that we now have into a much less stable peace. This question should certainly be an objective of any research into weapons appraisal. He also raises the question of the relationship between the ability to fight a conventional war and the probability of nuclear war. This also would seem to be a very legitimate subject of short-run research, though I am not sure myself what the outcome would be. Certainly our inability to fight a revolutionary guerrilla-type war in Vietnam only slightly increased the probability of nuclear war with the Soviet Union. Furthermore, there is a very general delegitimation of what might be called "colonial war" that makes it extremely difficult to pursue one to any politically successful conclusion, although it may take a few more examples before people are persuaded of this. An ability on the part of the United States to invade and conquer Iran would almost certainly increase the probability of nuclear war with the Soviet Union. This should certainly be a subject of research.

Dr. Bobrow's essential point, as I understand it, is that we cannot answer the question of how we get worldwide stable peace immediately, but what we can do is ask ourselves what changes in scientific knowledge and technology, and even in weapons technology, will move the system toward increasing the probability of peace and diminishing that of war. This seems to be a very sound point of view, even in the short run.

Dr. Bobrow also suggested that a paper of a very different kind could be written that would stay within the existing "normal science" framework in treating national defense. It might be that this could be done, but I could not do it.

Another important point which Dr. Bobrow makes is the necessity for studying the decision-making processes of national states with regard to unilateral national defense. I agree very strongly with this in spite of the difficulties that are involved. He also makes the extremely interesting point that, whereas the time horizon on technical innovations, particularly in the defense field, is apt to be from 20 to 60 years, our time horizon in social, economic, and political predictions is very much less than this. He suggests from 1 to 8 years—even 8 years seems optimistic to me. Unfortunately, I see no answer to this problem. Social systems are quite inherently unpredictable because of the fact that decisions are very frequently affected by quite random factors. They are also unpredictable because of our inherent inability to predict the future of knowledge or even of technology. If we could predict it, we would have discovered it by now. Information has to be surprising or it is not information. In social systems, information dominates the whole system and is merely modified by mechanical regularities. These considerations would suggest, however, that research and development in national defense are quite inherently pathological; that they cannot contribute to our security and must diminish it. If this is so, the urgency of finding a substitute becomes all the greater.

Dr. Coleman made some useful specific points which I have incorporated in the revision of the original paper. He again emphasizes the point that the Department of Defense operates essentially in the short run and that its demands for research and development are largely governed by this. In reply, I would argue that I think any short-run program must be made in the light of long-run probabilities, and that if these probabilities rise to a certainty of total catastrophe, there is no point in short-run optimization. This indeed would be "sub-optimization," that is, finding the best way of doing something that should not be done at all. "Sub-optimization" is one of the major sources of bad decisions in any field of human life.

Dr. Stieff also made some excellent textual points, some of which I have tried to incorporate. He felt that the whole point of view was too unfamiliar to most people to be readily understood. He also felt the need for expanding many of the ideas in the paper, particularly the concept of the threat system and of the instability of deterrence. His criticism would suggest the need for a substantial research project on threat systems in both international and domestic society, and I would certainly endorse the need for this.

Dr. Scribner shared many of Dr. Stieff's concerns, and raised the question of whether any assessment of new weapons should be done by an integrated group, which would include social scientists as well as physical scientists and engineers, to look at the impact on the total world social system. He also was concerned about how to translate these rather unfamiliar ideas into language that would be comprehensible to a wider audience. He was struck with the need for the study of the legitimation of threat systems.

One problem that did not come up in the discussion was that of the economic impact of the "war industry." A good deal of work has been done on this subject over the past 25 years, and there is fairly broad consensus that this is by no means an insoluble problem. The American economy especially is remarkably flexible; there is no sense in which a large war industry is necessary to produce full employment. In 1945-1946 we shifted about 30 percent of the economy from the war industry into civilian production without unemployment rising above 3 percent. In the early 1960s a fairly sharp reduction in the war industry (from about 9 percent to 7 percent of the Gross National Product [GNP]) was accompanied by an appreciable reduction in unemployment. In fact, the war industry—which has averaged about 7 percent of GNP in the past 25 years—has been a severe cumulative drain on the American economy, even greater in qualitative terms than the 7 percent would suggest because of its high technology. The loss represents an internal brain-drain that probably accounts for a significant part of the relatively poor growth performance of the American economy during this period.

A more difficult problem, which also did not come up, is the threat to the military subculture itself that the crisis in unilateral national defense implies. This threat is somewhat parallel to the crisis in religious subcultures that the rise of science created. Such threats are understandably sharply resisted, and creative adaptation to them is the key to survival. The potentiality for the transformation of military subcultures, such as is suggested, for instance, in Michael Harbottle's remarkable study of the United Nations' forces in Cyprus, *The Impartial Soldier*, is worthy of much serious study.[5]

In a larger context, national "defense" must be seen as part of a segment of the total world dynamic system which is concerned with the prevention of unwanted change. The social sciences in their normative mode have concentrated so much on the achievement of wanted change that they have almost totally neglected the problem of defense against unwanted change. This is unfortunate, for such a defense easily becomes pathological, as the psychological term "defense mechanisms" suggests. Nevertheless, defense in this sense is an entirely legitimate, and indeed a most important, problem in all areas of human life and interaction. The direction of the social sciences toward this kind of defense would be a most valuable widening of their agendas.

If indeed one dominant conclusion emerges from this discussion, it is that the agendas in the study of defense must be widened, and that the scientific isolation of the national defense establishment must be broken down. Otherwise, we are likely to continue to slide down a slippery slope toward the cliff of irretrievable disaster in major nuclear war.

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THE FIVE-YEAR OUTLOOK FOR SCIENCE AND TECHNOLOGY: SOCIAL AND BEHAVIORAL SCIENCES

A Report from the
Social Science Research Council

Introduction

According to the legislation that mandated it, the *Five-Year Outlook* for science and technology has two purposes. One is to inform the Congress of emerging areas of scientific and technological research that promise to illuminate problems of national significance. A second purpose is to identify those research topics and the conditions that facilitate innovative research that warrant special attention during the next five years. These two objectives have been met by the preparation of background essays on research in science and technology. With respect to developments in research in the social and behavioral sciences, the Social Science Research Council invited leading scholars in several different fields to prepare review articles.

Debates in the Congress on the level of research support for the social sciences frequently center on the usefulness of such research as the criterion for funding. Although a set of essays that emphasized the direct applications of social science research would respond to this demand and fulfill one of the *Five-Year Outlook's* legislated mandates, the essays would not reflect the breadth of knowledge that the social sciences can contribute to the understanding and resolution of social problems.

A broader perspective on social significance is outlined in the first chapter, and is illustrated throughout the five review chapters. This perspective rests on the premise that investigations of fundamental questions about human and behavior and social processes provide the data, theories, concepts, and methods that lead to informed decision-making in both public and private sectors. Moreover, those parts of social science specifically designed to evaluate public programs or to examine social problems derive methodological rigor and theoretical insight from research efforts conducted throughout the social sciences. The essays included here, therefore, review research that is characterized by scientific merit and momentum. These research areas also promise to illustrate areas of social concern, both in the immediate future and, more importantly, in the decade to come.

ESSAYS ON RESEARCH FRONTIERS

Under the guidance of a Steering Committee[1], five topics reflecting major intellectual currents in social and behavioral research were selected for extended treatment: relationships between behavior and physical health; influences on the social and emotional development of children; a changing perspective on individual development over the entire life course; statistical measurement of social change; and recent advances in survey technique and analysis. All five topics grow out of significant research in the social and behavioral sciences; all five hold promise for the illumination of major areas of national policy.

BEHAVIOR AND HEALTH

The essay on behavior and health reviews research on the implications of individual behavior patterns for health and physical disease. Behavior and health are linked in three principal ways: through the direct effects of psychosocial factors on tissue function; through the detrimental effects of life-style and habits on health; and through the responses of patients to symptoms and to medical treatment. In drawing on the research traditions of both the biomedical and the social sciences, this work on behavior and health illustrates the promise of research that occurs at the intersection of the social sciences and other disciplines. Other examples include research on sensation and perception, which draws on the fields of physics, biology, and psychology, as well as the development of computer software.

THE LIFE-SPAN PERSPECTIVE

The essay on the life-span perspective in social science research describes a general approach to research on individual development and social change rather than a well defined substantive area such as behavior and health. Underlying this approach is the view that human development continues throughout the life course and that individual characteristics and statuses are not fixed but continue to change. Research employing a life-span perspective has already altered many of our assumptions about old age, adult education, and the ways in which people of all ages adapt and respond to change. The essay also illustrates how seemingly unrelated research in several disciplines has contributed to the development of a cumulative research perspective. This perspective, in turn, has the potential to change theory and research in each of the contributing disciplines and to inform the development of social policy in almost all sectors of the government.

ADVANCES IN METHODS

The essay on methods for social surveys—somewhat more technical than the other essays—summarizes recent methodological advances on problems encountered in the design, collection, and analysis of large-scale social surveys. It also examines the uses of administrative data and the special problems posed by longitudinal surveys. Despite its technical nature, this is an appropriate and important subject for the *Five-Year Outlook* because of the government's substantial investment in statistics and survey research. This essay also demonstrates how the social and behavioral sciences, no less than the natural sciences, work systematically to improve their research tools and techniques.

STATISTICAL MEASUREMENT

The use and analysis of statistical data in social research are discussed in the essay on the statistical measurement of social change, a research tradition that dates back to the report of the Committee on Recent Social Trends established by President Herbert Hoover in 1929. The essay reexamines several social trends, such as the changing divorce rate, that have previously been misinterpreted; in particular, it considers ways in which the measurement of social change is affected by the analytical approaches employed, by changes in the concepts being measured, and by the accuracy of assumptions about the shape of future change. Research on statistical measures of social change represents a long-term collaboration and commonality of interests between the government and social scientists.

CHILDHOOD DEVELOPMENT

Research on children's growth and development has long been of interest to parents, schools, and agencies at all levels of government. Most past research, however, has concentrated on the intellectual or cognitive development of children. Recent work on their social and emotional development, the subject of the fifth essay, responds to the concerns of parents, educators, and policy makers, for it recognizes that intellectual growth is only one aspect of the development of children, one that is, itself, affected by social and emotional development.

The essay reviews recent research on the impact of parents, peers, and television on children's moral development and on the learning of cooperative and altruistic behavior. It considers such complex issues as how children acquire self-confidence, the motivation to help others, and knowledge of society's laws, rules, and norms. This research demonstrates the willingness of social scientists to explore some of the most difficult and elusive dimensions of human behavior, and is an example of a true frontier in the social and behavioral sciences.

OTHER CURRENTS IN THE SOCIAL AND BEHAVIORAL SCIENCES

The essays in this volume illustrate important achievements in the social and behavioral sciences. They do not, of course, exemplify all of the major advances; nor do they represent all of the diverse approaches, methods, and substantive topics that comprise these domains. Although it is not possible to sketch here the full range of research encompassed by the social sciences, it is useful, as a background for the chapters that follow, to note several types of research that have not been included in this volume.

POLICY RESEARCH

Both the findings and methods of the social and behavioral sciences are often applied to public policy, even if they are not part of "policy research." The defining characteristic of policy research *per se*—which is variously called applied research, policy analysis, or social research and development—is the intention of sponsors and scholars to provide advice or information on a problem situation that is external to the science itself. The research problems selected for attention are drawn from social problems (such as poverty, hunger, and unemployment) and, in addition, from policy problems. For example, one area of policy research, science planning, has a long research tradition, dating from the support for the first Science Advisory Board, in the 1930s, by the Social Science Division of the Rockefeller Foundation. Systematic social inquiry is expected to contribute relevant knowledge to public and private agencies responsible for designing ameliorative policies. A more extensive discussion of policy research is found in the first chapter.

INTERNATIONAL STUDIES

The findings and methods described in these essays are concerned with the behavior and attitudes of individuals and groups that are situated within nations or bounded by national societies. Equally significant are studies that examine phenomena derived from the interactions of nation-states; analyze relationships, institutions, and social movements that cross and transcend national boundaries; or attempt to assess cross-national evidence. Taken together, these three types of research—international, transnational, and cross-national—comprise most of what is included, in the United States, under the rubric of "international studies."

The American social science research community engaged in international studies is now in an important transition. During the past thirty years, foreign area studies have produced an impressive body of research on the societies and cultures of other areas of the world. Now, however, social scientists are moving beyond the kinds of questions about the nature of other societies, languages, and cultures that originally gave rise to area studies, and beyond the single country or regional focus that has prevailed historically in this research. In a world that is experiencing both increasing interdependence and fragmentation, there is understandably a growing interest among American social scientists in research that probes the significance of cultural boundaries, or that explores phenomena that cross and bridge such boundaries. Some characteristics of these kinds of research deserve special note.

Transnational research focuses on phenomena that are separate from nation-states, but always involve at least two of them. Although transnational phenomena are not new topics for research, recent changes—for example, the increased volume and diversity of people and goods moving across national boundaries or the development of large and embracing transnational institutions, such as the modern transnational corporation— have attracted increased attention from social scientists. Researchers have been examining the changing nature of transnational phenomena and their consequences for national states and international organizations.

Studies of the modern transnational corporation, for example, try to understand how its social organization enables it to take advantage of different national market conditions in making production and marketing decisions that will maximize benefits for the corporation. As more of these corporations have been based outside the United States, researchers have looked at the changing positions of national companies within the international environment, and at the effects of their decisions on national states. Social scientists have also been concerned with the changing circumstances of transnational phenomena, such as the implications of international competition for scarce resources. Other transnational phenomena which are foci of current social science research include religious movements, ethnic groups with transnational identities, and such agencies as the Red Cross and Amnesty International.

Most research on international phenomena focuses either on nation-states, or on phenomena derived from their interactions. Political scientists have long studied relations among nation-states and their impact on a variety of national problems. Now, responding to increases in the diversity and complexity of international relationships, social scientists are developing new theories and methods for studying the economic, political, sociocultural, and strategic interactions of nations. Examples of current international research topics include: global or limited warfare; international negotiations, treaties, and agreements pertaining to arms limitation, trade, migration, and other matters that frame and affect the activities of transnational actors; and the operations of global and regional international organizations such as the United Nations, the North Atlantic Treaty Organization, and the Asian Development Bank.

Cross-national research compares similar phenomena in different cultural settings. Often the boundaries of such phenomena are nation-states; however, they may also be regions or culture groups. The growing interdependence of nations requires a greater understanding of phenomena in different historical and cultural settings. Central to such an understanding is the capacity to make effective comparisons, to identify the commonalities as well as the uniqueness of particular circumstances. Cross-national studies of work, family, ethnicity, religion, and political parties are advancing our understanding of the behavior and experiences of individuals, groups, and institutions beyond what can be learned from studies of single societies.

Although each of these modes of social science research is distinct, they are often combined in the study of particular phenomena. For example, in studying a specific ethnic group it may be important to examine its distribution within and across national boundaries, international regulations governing the migration and travel of ethnic group members, and comparative indicators of the experiences of members in different historical and cultural situations. Similarly, in order to understand the activities of transnational corporations in a given country, it may be necessary to examine the international and domestic regulations that structure and regulate their activities and the range of their activities in other national settings. Studies that combine transnational, international, and cross-national research comprise an important and growing part of American social science.

MACRO RESEARCH

The essays that follow focus primarily on individuals as the units of analysis. Much of social science, however, is concerned with collectivities, institutions, and organizations. During the past several years social and behavioral scientists have directed increasing attention to the development of conceptual approaches and methodologies for studying such collective institutions.

Illustrative of this kind of work is the growing body of theory and research on states and social structures. Instead of regarding the state simply as a reflection of other social forces, recent social science research has come to view the state as a relatively autonomous actor, both influencing, and being influenced by, the society. This new research is attempting to define state structures and to identify the conditions that affect the development of these structures and capacities.

Studies of state structures may proceed by examining their organizational sub-units, bureaucratic patterns, and the legal norms that shape their interaction. Studies of states' varying abilities to achieve their objectives are investigating the potential relationships among different capacities: for example, whether a state's ability to defend its territory or preserve social order is related to the capacity to transform society, to achieve economic development, or to redistribute wealth. In seeking to understand the differential capacities of states, researchers are examining relationships between the state and other groups and institutions in society, including other nations. Thus, some scholars attribute the recent economic successes of Brazil to the formation of new bonds between the state and different factions of the elite class; and some experts on Taiwan and Korea point to the importance of the countries' positions in the world economic system as a key to understanding their rapid economic growth. These new approaches to the study of state and society have already stimulated promising research on such topics as the politics of economic development.

APPROACHES AND METHODS

The chapters that follow illustrate some—but not all—of the important methodologies in the social and behavioral sciences. These essays represent dominant research traditions of American social science; as a result, they do not reflect challenges to some of the central assumptions of mainstream social science from several new approaches.

The dominant tradition of American social science uses as its basic data systematic observations or measures of individuals or groups, extracted for analytical purposes from their larger context. These observations are organized into discrete variables, and hypothesized causal relationships between them are tested by examining the impact of changes in one variable on changes in the others. This type of social science is modeled on the physical sciences. It emphasizes the use of quantitative data, especially survey data, and to a lesser extent, experimental data. Its underlying assumption is that an understanding of relationships among significant variables will enable society to develop the means for alterations and improvements.

In recent years, other approaches to social science, such as structuralism, ethnomethodology, and "interpretive" social science, have challenged the aims and assumptions of this dominant tradition. The nature of these challenges can, perhaps, be illustrated most effectively by examining the interpretive approach or explanation in greater detail.

Interpretive social science seeks a detailed understanding of the meaning of actions, customs, events, and institutions to the individuals and groups that perform and participate in them. It seeks to explain not by cause or universal law, but by understanding particular wholes.

Social scientists working in this tradition typically draw on case studies of individuals and small groups, and many of their methods are taken from the humanities. They have drawn increasingly upon techniques of literary analysis and on the uses of metaphor, narrative, and scripts as tools for understanding social behavior. Thus, a particular domain in the life of a person or group (e.g., politics, the occupational world, the family, or religion) can be examined using the techniques of literary analysis. The goal is to explain the meaning of the symbols that the individuals and groups depend on to organize their lives.

This new approach within American social science is provoking controversy because it redefines the objectives of the enterprise, the kind of knowledge desired, and the appropriate ways of obtaining that knowledge. Although it derives from "academic" sources, this new approach has its practical uses: knowing what and how people think about their families or jobs is important information in any effort to bring about improvements in living conditions. The results of this and other recent approaches in the social and behavioral sciences are just beginning to emerge. Yet the research literature they have already generated is certain to influence the kinds of materials collected and analyses undertaken by social scientists generally.

INSTITUTIONS OF THE SOCIAL SCIENCES

Much of the social and behavioral science research that is carried out in the United States is undertaken by faculty members at the nation's research universities. Research is also conducted in a variety of centers and institutes, some free-standing and some affiliated with universities. These are the social science equivalents of the laboratories and observatories of the physical and natural sciences. There are, in addition, several national organizations that provide special services to the social sciences, both to individual scholars and to the research centers and institutes. A third category of institutions that play a significant role in social science research are the public and private institutions that provide financial support to individual scholars, universities, and other organizations. This concluding section of the introduction to the *Five-Year Outlook* provides an overview of the institutions that house, foster, and support the social sciences.

NATIONAL ORGANIZATIONS

There is no official umbrella organization for the social sciences in the United States, but each discipline has a national professional association to which most scholars in the field belong. These associations sponsor annual meetings and the publication of journals, maintain professional and ethical standards, and publicize grant and fellowship opportunities. Only rarely do they become directly involved in research (beyond the publication of results); instead, they focus on the professional lives of their members.

In contrast to these professional associations are three national organizations that are directly concerned with the research of social scientists.[2]

The Social Science Research Council (SSRC), founded in 1923, was created by representatives of the seven major social science disciplines for the explicit purpose of advancing research. Governed by a board that is partly elected by the professional associations, and administered by a president and a staff of social scientists, the Council seeks to advance research in the social sciences in a wide variety of ways: it appoints committees of scholars to set priorities and make plans for critical, generally interdisciplinary areas of social science research; it seeks to improve research capabilities through training institutes and fellowship programs; it works to support individual research through the provision of postdoctoral grants; it convenes research conferences that are often interdisciplinary and international; and it sponsors the preparation of books and other research publications that often result from these activities.

The Assembly of Behavioral and Social Sciences (ABASS) is one of eight major program units of the National Research Council, the principal operating agency of the National Academy of Sciences. The Assembly provides the primary forum for the behavioral and social sciences in all National Research Council endeavors and is actively involved in efforts to relate the behavioral and social sciences to public policy. Governed by a board of social scientists and administered by an executive director and a professional staff, its work is carried out largely through committees of scholars. Generally, its activities are initiated not by scholars but by officials of the federal government, for it is on the government's behalf that the National Research Council is chartered to conduct and sponsor research.

The Center for Advanced Study in the Behavioral Sciences, founded in 1954 with funds from the Ford Foundation, provides about 50 scholars a year with the quiet, the library resources, and the freedom from teaching and administrative responsibilities that are conducive to research and writing. Typically, Fellows at the Center either plan their next research project or complete a book about their latest one. In recent years, however, the Center has taken a more active role in planning and guiding new areas of research, primarily by sponsoring conferences and workshops. It is considered an honor to be invited to be a Fellow at the Center, which remains both a symbolic focus of high quality research and a locale where this research is often generated.

RESEARCH INSTITUTES

There are hundreds of university-based social research institutes in the United States. Most are small, serving the research interests of a relatively few faculty members and a larger number of graduate students; a few dozen are more extensive, with specialized programs. Of these, two are outstanding both in size and in the quality of research they produce: the Institute for Social Research at the University of Michigan, and the National Opinion Research Center at the University of Chicago.

The Institute for Social Research (ISR) at the University of Michigan was founded in 1946. It has since become the nation's largest and most diversified social science institution situated on a university campus. The Institute consists of a number of subsidiary organizations; the largest and best known of which is the Survey Research Center. The Center, in turn, is widely known for its panel studies of voters in national elections, its surveys of consumer expectations, and its research into large-scale organizations.

The National Opinion Research Center (NORC) was founded in 1941 at the University of Denver, where it established a nationwide staff of trained interviewers. In 1947, NORC moved to the University of Chicago, where it has focused on methodological development and surveys conducted on behalf of a wide variety of private and public sponsors. Among its projects, it currently administers the General Social Survey, which is a periodic attempt to obtain standardized information about the general public.

Among the research centers and institutes affiliated with universities, the centers for the study of foreign areas deserve special note. Where there are concentrations of faculty with expertise on a particular geographic region, there is often an administrative unit such as an institute or center. More often than not, the unit is a Title VI Center, i.e., it receives federal funds authorized under Title VI of the National Defense Education Act of 1958. The importance of these centers extends beyond the administrative support they provide for scholars: they combine the functions of teaching and research—to the improvement of each—and they provide an environment for interdisciplinary and collaborative teaching and research.

There are many important social research institutions that are independent of universities. Most are nonprofit, but one, Abt Associates, located in Massachusetts, is a large and successful profit-making institute, supported chiefly by government contracts. Major nonprofit institutes that conduct or support a substantial amount of social science research include the American Enterprise Institute (Washington, D.C.); the Brookings Institution (Washington, D.C.); the Hoover Institute (Stanford, California); the National Bureau of Economic Research (Cambridge, Massachusetts); The Rand Corporation (Santa Monica, California); and the Research Triangle Institute (Research Park, North Carolina). Many U.S. government agencies conduct social science research, including the Agency for International Development, the Department of Agriculture, and the National Institutes of Health. Social research is also conducted by various United Nations agencies throughout the world; in the United States, the Population Division and the United Nations Fund for Population Activities are the most important.

SUPPORTING INSTITUTIONS

In addition to the research institutes and national organizations, there are a variety of public and private institutions that make social research possible by providing financial support to individuals, universities, and other organizations.

Notable among the many private organizations that have supported social science research are the Ford Foundation and the Rockefeller Foundation. By no means identical in orientation, emphasis, or focus of activities, both foundations are keenly interested in international relations and world problems, and in social, economic, and demographic research (although their concerns are not limited to these areas). Some staff research is conducted at each foundation, but both organizations work primarily through grants to institutions and fellowships to individuals. The involvement of these and other foundations in social science research extends beyond the provision of financial support. By setting their own institutional priorities, and deciding where and how their resources should be committed, they also exert (directly or indirectly) an important influence over the direction of social science research.

Of the other private sources that support research in the social sciences, prominent mention should be given to the Andrew W. Mellon Foundation, the Alfred P. Sloan Foundation, and the Russell Sage Foundation. In addition to support, these organizations also provide significant leadership in the social sciences.

Other major sources of support for the social sciences are the various agencies of the federal government. Established by law in 1950 to assume public responsibility for developing basic research in the physical and biological sciences, the National Science Foundation (NSF) now encompasses applied research in these areas as well as basic and applied research in the behavioral and social sciences. In recent years, support for the social sciences has accounted for about 7% of the total NSF budget. In addition to supporting research conducted in the United States, NSF has an impressive international program which encourages and stimulates cooperative science activities by supporting joint research projects and seminars, exchanges of scientists, joint commissions for scientific and technological cooperation, and participation in international scientific organizations. Many of these activities operate under formal bilateral or multilateral agreements with foreign countries. For more than a decade, through its Science in Developing Countries Program, NSF has supported cooperative research projects involving scientists from the United States and developing countries. Addressed to problems of common interest, the projects supported under this program often include those in the social sciences.

Another major source of federal funds, the National Endowment for the Humanities (NEH), was created by Congress in 1965 to support research, education, and other public activity in the humanities. The Endowment supports research in cultural anthropology, sociology, political theory, and international studies—in brief, social science subjects which connect with humanistic topics or research methods. The Endowment's programs are administered primarily through divisions such as the Division of Research Grants which provides support to institutions and individuals for research projects as well as for the preparation of important research tools such as bibliographies.

Sometimes agencies combine resources: one example is the program supported jointly by the NSF and NEH to foster research, education, and other activities on the value implications of advances in science and technology. This program also encourages collaborative, interdisciplinary work between humanists and social and behavioral scientists on value questions arising from emerging social, economic, and technological issues.

Another prominent example of federal involvement in social science research is the Fulbright Program, established in 1946 under legislation introduced by former Senator J. William Fulbright. Designed to increase mutual understanding and knowledge between the United States and other countries, the Fulbright Program does not itself carry out research, but instead encourages the exchange of ideas and knowledge through exchanges of students, teachers, and scholars. Each year, more than 3,300 grants are awarded to individuals. In 1979–1980, approximately 700 scholars from 75 countries came to the U.S. to lecture and conduct post-doctoral research; at the same time, 500 American scholars and professionals were sent to 100 nations. These individuals included a significant number of economists, political scientists, and sociologists. The Fulbright Program also awards predoctoral fellowships through such institutions as the Committee for Scholarly Communication with the People's Republic of China (CSCPRC), which administers the U.S. Government's scholarly exchange program with that country, and the International Research and Exchanges Board, which administers the Fulbright exchanges with Eastern European countries and the USSR.

This brief introduction was intended to give the reader a sense of the intellectual and institutional context of social science research. Narrowing this broad context to a set of six essays was difficult. In the end, it was decided to select five subjects for extended treatment which were illustrative of exciting new directions or cumulative research progress, even though those five topics could never be representative of the full range of social and behavioral research now underway. The sixth essay, with which the set begins, carries the introductory theme one step further and deals with the social significance of research in the social and behavioral sciences.

NOTES

1. The Steering Committee is made up of Kenneth Prewitt (Social Science Research Council), Robert McC. Adams (Committee on Basic Research in the Behavioral and Social Sciences of the Assembly of Behavioral and Social Research, National Research Council), and Gardner Lindzey (Center for Advanced Study in the Behavioral Sciences). Roberta Balstad Miller served as SSRC staff.

2. Because of the unusual role of these three organizations in social science research, a representative of each served on the Steering Committee for the preparation of these reports.

1 Assessing the Significance of Social Science Research

Kenneth Prewitt

INTRODUCTION

The Five-Year Outlook on science and technology is intended to bring to the attention of the Congress research areas and disciplines that are both scientifically and socially significant. Within the sphere of our responsibility, the behavioral and social sciences, we have chosen five substantive areas for their demonstrated scientific merit as well as for their obvious importance to public well-being. This chapter provides a more general statement about the relationship between social science research and the public welfare. This statement is constructed, first, in terms of six principles that enable us to assess the social significance of research; and second, in terms of the outlook for the continued significance of this research.

SIX PRINCIPLES OF SOCIAL SIGNIFICANCE

The six principles of social significance discussed are constructs, systematic information, empirical regularities, practical applications, market value, and public policy uses.

CONSTRUCTS

The behavioral and social sciences have produced numerous interpretive constructs which explain, interpret, and deepen our understanding of social phenomena that previously were incorrectly or inadequately comprehended. The list of such constructs is long: human capital, span of control, the unconscious, gross national product (GNP), acculturation, and reference groups—to name but a few. Social science research does not, of course, invent these phenomena, but it does invent the constructs that help us to see them more clearly. The calculation of the unanticipated costs of market economies predated the concept of externalities, but the introduction of the concept has increased society's understanding of both resource depletion and unintended environmental consequences.

A more extended illustration of the use of social science concepts can be drawn from developmental psychology and the conception of childhood offered by Jean Piaget and his followers. Before Piaget's research, it was generally assumed that the infant was passive, unaware, and insensitive. Indeed, less than one hundred years ago, it was thought that infants were born deaf and blind. But infancy research has now demonstrated that infants are person-like and resilient. Not only are babies born with distinct visual and auditory abilities and preferences, they are also born with already evident individual differences in temperament and personality. Knowing this, aware parents can structure an infant's environment so as to make it interesting and appropriate to the child's age and temperament. For example, parents now realize that certain infant behaviors are forms of communication. The concepts of developmental psychology help us understand the ways in which infants are curious and active and, in their own terms, knowledgeable and competent.

Whether from psychology, economics, sociology, or anthropology, social science concepts bring the previously inaccessible to social consciousness. In this sense, one of the principal functions of research is to lessen ignorance or incomprehension and to provide constructs with which to interpret and understand reality. But it is a truth of science, readily acknowledged, that it expands the frontiers of ignorance even as it expands the frontiers of knowledge. To explore the workings of the human mind, the history of a society, the meaning of a culture, the functioning of an economy, is inevitably to ask increasingly profound and complex questions. Science proceeds as much by the new questions it raises as by the prior questions it answers. In this process, research produces concepts. Ironically, the social sciences seldom receive credit for these contributions to our intellectual life because the constructs, once labeled, soon become conventional wisdom.

SYSTEMATIC INFORMATION

Social science, through its emphasis on social measurement and observation, helps bring systematic information to bear on difficult questions of judgment and choice. The social sciences, collectively considered, are among the great observational sciences of mankind, rivaling in scope, variety, and significance such other observational sciences as astronomy and geology. Advanced industrial nations are commonly described as information societies in reference to their systematically collected information about the human as well as the physical environment. Human actions and the meanings attached to them constitute the most dynamic and complex of all those environments in which markets trade, banks invest, businesses produce, governments govern, and families make plans for the future. Monitoring the ever-changing human environment is a task approached through a variety of tools and disciplines of the social sciences: economic indicators, demographic trends, national statistical systems, historical research, time series analysis, input-output matrices, developmental psychology, area studies, and political geography are all examples.

Demography, the social science concerned with the changing size and composition of human populations, is a source of information widely used in both the public and the private sectors. Commercial enterprises make heavy use of population data and demographic projections in decisions about where to locate an office, factory, or retail outlet and about the kinds of products to produce and the nature of the marketing strategy to follow. The age distribution of the population and changes in the composition of households have far-reaching implications for commerce, labor markets, social security programs, crime deterrence, school enrollments, transportation needs, demands for housing, and recruitment to the armed forces.

The information base for which the social sciences can claim some credit extends well beyond national statistical systems or demographic projections. It includes what a society is able to learn about its own past through the research of historians, and what it learns about the cultures and aspirations of other people through the efforts of scholars who study other societies. It was to anthropologists that military and political leaders turned in the 1940's when the leaders realized how little they knew of the South Pacific islanders and their culture. Forty years later this tradition continues, as corporate leaders of multinational firms draw upon scholarly expertise for information and analysis pertinent to distant markets and foreign supplies of raw materials.

Care must be taken to distinguish information from the judgments that take information into account. Social science analysis is not a substitute for judgment and choice, which are matters for the deliberative processes of society or the moral reasoning of individuals. Policy decisions by governments, investment decisions by businesses, career decisions by individuals—these and other judgments can be aided but not predetermined by information. Information is not a substitute for practical judgment, although, if reliable, it can add practicality to the judgment. And information is not a substitute for moral choices, although it can contribute insight into the conditions under which such choices must be made.

EMPIRICAL REGULARITIES

Research has discovered many empirical regularities which give structure to social processes. Social science does not invent these regularities; they exist prior to the research that discovers them, just as DNA, quarks, and the source of the Nile existed prior to their mapping by scientific explorers. But social science does provide an increasingly rich and dense mapping of demographic and social structures by uncovering empirical regularities: the stable pattern of age-related mortality in all societies, the differential voter turnout between presidential and off-year elections, the relative invariance in markedly different societies of occupational prestige hierarchies. Each of these regularities has consequences for choices made by individuals and organizations: age-related mortality rates have implications for public health programs in developing societies; differential voter turnout has implications for campaign strategies and electoral reform;

occupational prestige hierarchies have implications for educational policy and wage structures.

One significant empirical regularity at the frontiers of research concerns the differential age trajectories of fluid and crystallized intelligence. *Fluid intelligence* refers to the capacity to reason with abstract symbols and the ability to invent unconventional problem-solving strategies. It develops early in life and is now thought to be the basis for other forms of intelligence. *Crystallized intelligence* refers to the mental skills necessary for effective functioning within the conventional mores and symbols of one's community. A low level of crystallized intelligence implies difficulty in understanding and being able to retain a written or oral message. Fluid intelligence has to do with whether a person can think his or her way into a novel situation or out of an unconventional problem; crystallized intelligence has to do with whether a person can deal with such standard problems as how to balance a checkbook or read instructions about the maintenance of sophisticated machinery.

Fluid and crystallized intelligence appear to have different development profiles, an empirical regularity which, if confirmed through repeated testing, will have deep implications for issues as diverse as the sequencing kill instruction in early schooling, the training of military personnel for using increasingly sophisticated technical equipment, mid-career occupational change, educational and employment opportunities for retired persons, and the preparation of age-related educational materials.

For five decades, social science has revealed empirical regularities that are now routinely and matter-of-factly taken into account by governments, businesses, organizations, and families. These are true discoveries in the sense that the regularities exist prior to research, but can only become part of the map of society if the discovery process occurs.

PRACTICAL APPLICATIONS

Social science research findings are frequently applied in practical situations. Sometimes the application is direct. Often it occurs after modification to meet particular practical goals. An example of the latter is behavior modification therapy, now widely used in personal health regimens, the treatment of neurotic and psychotic disorders, and substance abuse prevention. Behavior modification derives from earlier research on operant conditioning. The principles from this research have been tailored to meet behavior modification goals, but they exist independently of the many applications now being made. Research in cognitive psychology and memory provides many other examples. Reading programs have been redesigned as a result of findings from cognitive psychology and linguistics. Memory research has been put to growing use by the police and the courts in assessing eyewitness testimony.

Research on attitude formation has found many practical applications in marketing. Research in decision theory and organizational management is routinely translated through business school curricula and eventually applied in corporations and businesses. A leading American student of Japanese management has noted that the large Japanese literature on management and industrial work draws significantly on translations and analyses of Western scholarship. Parents and school teachers are making practical use of child development research when they take guidance from the many handbooks on parenting and child behavior.

Social science research, of course, can be misapplied. This can result from poor research design or hasty generalizations: social scientists have no more claim to perfection than do governments, businesses, or parents. It can also result from misunderstandings by those who apply social science findings. These difficulties notwithstanding, the practical application of the theories and methods of social science far exceeds what is commonly assumed, no doubt because the institutions and persons making use of research results are often unfamiliar with the source of that which they apply.

MARKET VALUE

One measure of the practicality of social science methods and intellectual constructs is their flourishing in free market economies. The commercial sector of the United States and other advanced industrial nations has invested heavily in technologies whose roots are in social science research. Demographic analysis and projections have already been mentioned. Other examples are standardized personnel testing, rooted in psychometrics; economic forecasting models, rooted in econometrics; man-machine system design, rooted in both physiological psychology and information science; market research, rooted in sampling theory and survey research; management of foreign exchange risks, rooted in international economics and risk analysis; and political polling, rooted in voting studies and election analysis. As is often the case, the industries marketing these technologies are seldom familiar with their origins in social science research. And it would overstate the case for social science to claim full credit for such multi-million dollar industries as econometric forecasting or standardized testing or demographic projections, but it does not exaggerate to observe that none of these industries would have developed in the manner or at the rate it has in the absence of earlier social science research.

More generally, social science research and training have contributed to the human capital resources of the society. One source of the comparative advantage of the United States in the international economy has been its investment in the human skills and knowledge that produced global marketing, financing, and management systems. Sustaining this advantage will depend upon expanding our understanding of the international flow of labor, capital, resources, and commodities. It will depend upon the managerial capacity to plan and organize transnational systems of distribution and financing. In short, it depends upon the type of intellectual resources and knowledge to which an internationally oriented social science has made, and will continue to make, a contribution.

PUBLIC POLICY USES

Social science research methods have been widely used in the public policy process. Such applications include the deliberate design of studies to inform or evaluate a policy choice. More often, however, the methods and results of social science research enter the public policy process in more indirect ways. Consider the national statistical system of the United States, which is the foundation for numerous federal and state policies in health, housing, education, welfare, commerce, and industry. This national statistical system is constructed largely on the methodology of sample surveys as developed over more than a half-century by statisticians, sociologists, economists, psychometricians, and related survey specialists. Economic and social indicators, which measure the performance of various sectors of society, are intellectual inventions of the social sciences working in close partnership with government and industry.

The contribution of social science to public policy extends well beyond techniques of collecting statistical data. Statistical information is not better than the concepts that guide its collection and organize its application. Social science is often the source of these concepts. A case in point is information on labor market behavior, which was reconceptualized in the 1930's and is in the process of being reconceptualized again. Before the Depression, government statistics on the work force reflected the number of people with a gainful occupation. Using this concept, it was not possible to get a satisfactory count of the number of people needing jobs, in part because of the exclusion from the working force of many occasional workers and those entering the employment market for the first time. To fashion policy during the 1930's, the government needed a count of the total number of people seeking jobs. The working force concept was replaced by a new concept, the "labor force," which included everyone in the population above a given age who, during a specified period, actually had a job or was seeking work for pay. This concept has guided the collection of labor market statistics ever since.

Research in the 1980's suggests there is a need to adjust economic and demographic statistical series again. Social scientists are now documenting the existence and apparent permanence of an informal economy and system of production. Some estimates, for example, suggest that unreported income could amount to 10 percent of the gross national product. Research on the informal labor market helps to clarify patterns of intra- and international labor migration. It casts issues of unemployment in a new and sharper light. It also raises questions about the accuracy of national measures of economic growth and productivity. Recent evidence indicates an explosive growth in employment in the service and light manufacturing sectors, much of it hidden from the present accounting system. It is research of this sort that can lead to a reconception and improvement of the national reporting system. A program to combat unemployment through reindustrialization, for instance, will miss its mark if it is based on poorly conceptualized labor market statistics. Thus, social science research contributes to public policy not just data collection techniques but also ways to think about the kinds of data that are needed.

In some instances, the government has asked social scientists for research explicitly designed to aid in the implementation or rejection of public policy alternatives. A prominent example of such research is the large-scale social policy experiment. Just as the federal government has considered major reforms in health, housing, and welfare policies, it has sponsored experimental programs in these areas to evaluate in advance the effect of potential national programs. Among these experiments have been programs for income maintenance, health insurance, and housing subsidies. Similar research projects, on a somewhat smaller scale, have assessed programs for employment training, criminal rehabilitation, and preschool education. Concepts and methods from the social sciences have been used in designing these studies, in collecting the data, and in interpreting the results.

Often there is neither time, resources, nor inclination to design a study relevant to a specific policy choice. In such circumstances, social scientists are frequently asked to review the relevant research literature and provide informed judgments about the implications of existing findings for the policy under consideration. This task is difficult and delicate because the criteria for generalizing from such findings are stringent. The task illustrates the importance and closeness of the relationship between policy research and the development of theory and methods within the social science disciplines. Policy scientists must combine conceptual and methodological skills from a diversity of disciplines and must organize these resources, usually within a short time, to address policy issues. Because the quality of policy research ultimately depends on the quality of the basic research skills and knowledge available, the usefulness of the policy sciences will depend on the development of the social sciences more generally.

Social science contributes further to the policy process by the ways in which it frames questions and approaches issues. It is not accidental that the phrase "unanticipated consequences," now a term in everyday vocabulary, was introduced by a social scientist. Social scientists are trained to expect second and third order consequences of actions planned with other ends in view. The unintended consequences of an intervention in a complex system can be at odds with and even detrimental to the intended effect.

Consider the bonus system underlying American management practices. Rewards are based on current profits, which encourages a short time horizon. The bonus system can operate, therefore, as a disincentive to long-term research and development strategies, which are presently needed for American industry. This perverse incentive is brought to our attention by economists whose intellectual approach sensitizes them to look for it. They have now been joined by psychologists who study choice situations. Psychological experiments demonstrate that risk aversion rather than risk taking is encouraged in choice situations such as those presented by the bonus system employed by many American corporations.

Other examples of unintended consequences are to be found in the many studies of government regulations conducted in the past decade. Many of these studies have shown that regulations may encourage rather than discourage the behavior they are designed to control. These studies, widely published in social science journals, are now playing a role in reducing the extent of government regulation.

Social science research does not determine policy. Policy is a matter of deliberation; it is an accommodation of diverse interests and the creature of social values; it is an exercise in moral choice and political judgment. But social science can hold up a mirror to society—one which reflects the multiple dimensions of social problems, the complexity of the economic system, the multiplicity of interests and human aspirations, the strengths and weaknesses of institutions. Making public policy is difficult under the best of circumstances—whether a program is being initiated, reformed, or abolished.

Policy decisions involve a guess about what causes people and institutions to do the things they do. Wrong guesses are costly—in wasted public resources, in public suffering, in missed opportunities to do the things differently. No decision process can guarantee right guesses. But the odds are increased if the guesses are as educated as our understanding of human behavior and social institutions allows. The social sciences attempt to make contributions to the craft of public policy-making by enlarging society's warehouse of educated guesses.

THE SIGNIFICANCE OF SOCIAL SCIENCE: AN OUTLOOK

An outlook or prognosis must start with an understanding of the past. The historical record of social science is quite clear and extends over a half-century—the period that marks the growth of the social sciences in the United States. For over 50 years, social science has focused a large share of its research resources and intellectual attention on the issues which have been of deepest concern to the society.

The story starts toward the end of the 1920's, when President Herbert Hoover organized large numbers of social scientists in the preparation of *Recent Social Trends* (President's Research Committee on Social Trends, 1933), two volumes reporting on the many facets of society affected by World War I and the Depression. Throughout the 1930's, social science investigations were concerned with those topics brought to attention by the efforts of society to deal with the Depression: social security, internal migration, unemployment relief, agricultural prices, and labor market behavior.

In the 1940's, not surprisingly, social scientists were pressed into government service and they turned social science concepts and methods to war-related questions: civilian morale, the analysis of enemy propaganda; studies relevant to the recruitment, training, management, and eventual discharge of the armed forces; the effects of the strategic bombing of Germany and Japan.

In the 1950's, as the pre-war colonial empires disintegrated and the U.S. became strategically and economically involved with new nations around the world, hundreds of scholars went abroad to study the cultures and languages of the newly independent nations. They came back to establish university area centers and other institutions for international studies which remain to this day the envy of governments and academic communities around the world. The 1950's were also a decade of expanded development of strategic studies—again in response to the international role which the U.S. found itself playing.

The domestic ferment of the 1960's was mirrored in a growth of interest among social scientists in race relations, urban problems, schooling, internal migration, as well as immigration. The 1960's were also a period of broader federal involvement in the delivery of social programs, and social scientists were called upon to improve their survey research methods and to design complex social policy experiments.

Two trends of the 1970's merit note. Largely because of the great number of new social policies initiated in the 1960's, there was a need for the systematic evaluation of programs such as Headstart. Social science responded to the challenge by establishing specialized methods for evaluating the consequences and benefits of particular policy interventions. In the 1970's, there was also a growing concern that government efforts to regulate economic and social activities were not working as intended. This concern was voiced by economists, political scientists, and sociologists, whose research was to become source material for the successful presidential candidacy of Ronald Reagan.

This sketch does not pretend to be a history of the social sciences in the United States. Much was happening during the last fifty years that is not captured by the particular themes stressed. Though incomplete, the sketch does illustrate an important truth about the public role of the social sciences. A large share of social scientific resources has always been devoted to the issues which are of the deepest concern to the society. This has been true whether the funding is from private sources, as it was in the early years, or from public sources, as it increasingly has been in later decades. It has been true whether the research is conducted largely in universities or in specialized research institutes—and in recent years the mixture has tended to favor the latter. It has been true whether the research is labeled basic or applied. And it has been equally true under Republican and Democratic administrations.

Another observation emerges from the historical sketch. Social science never has been, and is not likely ever to be, in a position to create the national agenda. Far more powerful currents than social science research determine the issues that society will emphasize. These more powerful currents affect what social science studies, just as they affect election returns, policy reforms, business decisions, media attention, and citizen attitudes.

It is the lessons we learn from history that provide the basis for anticipating the future. For five decades social science, as a major part of its research activity, has attempted to contribute to society's capacity to understand and cope with its most central concerns. The next decade will witness a continuation of this commitment. Specifically, we expect social science to address questions of social and economic innovation in a broad, sustained, and serious manner.

The nation today stands in need of innovations that will contribute to economic growth, improve the workings of the governing process, and release the creative energies of its citizens. These innovations will spring from the imaginativeness and inventiveness of individuals working through a large number of private and public organizations. If successful, the innovations will do for the next stage of America's economic growth what, for example, the development of the modern business corporation did for industrial growth in the nineteenth century. By facilitating the pooling of resources, the centralization of management, and the incurring of joint debt while minimizing individual risk, the corporation allowed the accumulation and management of resources needed to take advantage of the economies of scale offered by new technologies in manufacturing and transport. The U.S. has benefited enormously from those innovations it has borrowed, such as the corporation (initially borrowed from Europe, then extensively developed here). This country has also produced its own list of impressive social innovations, ranging from the very general (the constitutional doctrines of federalism and the separation of powers) to the more specific (research universities, the assembly line, or the federal withholding tax).

If there is to be a search for new social innovations, what role is there for social science?

First, social science can increase understanding within society of the social nature of many innovations. We speak easily of the social impacts of technological and engineering developments, but have a less certain grasp of the technological and engineering impacts of social innovations. We see the social consequences of the private automobile, primarily a technical innovation, more easily than we see the technical consequences of the assembly line, primarily a social innovation.

Second, research can accelerate the understanding of social inventions. Here there are several obvious points, all of which have begun to receive research attention. (1) Social science cannot predict the success of a particular innovation, but its theories can help to establish the boundaries within which innovations might reasonably be attempted. A reindustrialization program that fails to take account of both the informal labor market and the hidden economy is no more likely to work than a psychiatric therapy program that ignores unconscious motivation. (2) Social science can evaluate whether an innovation has in fact, worked. This is important because failing to detect poor innovations is costly in terms of wasted dollars and lost opportunities. For example, research on the success of recent social and medical innovations concluded that, when put to trial, only about 50 percent of these innovations were successful. (3) Social science can conceptualize and develop measures and studies of social invention—the development of new economic and institutional forms, new ways of performing common tasks, achieving consensus, arriving at joint decisions. (4) The factors affecting creativity and competence are likewise open to study. Much more should be known about the characteristics of cultures, cultural contacts, societies, groups, and institutions which contribute to the production of innovations of a social or technical nature. (5) More specifically, social science can conduct research on the pay-off of different forms of research and development. Frederick Mosteller, in his 1981 presidential address to the American Association for the Advancement of Science, reviewed the role of research and development in practical advances in both weaponry and biomedical therapies. He found that such advances "require not just one innovation or breakthrough, but a bundle of them, often as many as a dozen." Because of this, "there is a substantial period . . . between a basic science innovation and its use in weaponry or therapies."

Finally, in some instances, social science itself will be the source of a social innovation. Examples have already been provided: econometric forecasting, sample surveys, standardized testing, demographic projections, management strategies in complex organizations, operant conditioning, input-output matrices, man-machine system design, cost-benefit analysis, and many others.

The study of social innovations will not, of course, occupy all the research attention of the social sciences, just as not all social scientists worked on Depression-related themes in the 1930's or on war-related issues in the 1940's or became area scholars in the 1950's. Other issues that will command attention—such as the emphasis on transnational phenomena, the study of behavioral medicine, the improvement of statistical measurement, the discussion of basic epistemological principles—are noted elsewhere, in the materials prepared for the *Five-Year Outlook*. But innovations will become an increasingly important research theme because the social science research community in the 1980's, as in the previous five decades, will focus on those issues that are of most concern to the society and its future.

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2 Behavior and Health[1]

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SUMMARY

The study of behavior and health draws upon the research traditions of both the biomedical and the social sciences. Interest in this field has grown from the recognition that many of the health problems most common in our society are strongly influenced by psychological stress or by personal habits such as cigarette smoking, diet, or levels of physical activity. Once a disorder has developed, behavior is also important in treatment and recovery. Purely biological explanations of disease have not proven adequate to account for the development of chronic illnesses or why some individuals are more susceptible than others to particular types of disorders.

Recent social and psychological research on medical problems explores basic *mechanisms* linking behavioral and social processes to disease states. This approach integrates behavioral science principles with biomedical knowledge of the disease being studied.

The mechanisms linking behavior to physical illness fall into three broad categories. The first involves changes in tissue function brought about by direct exposure to psychosocial stimuli, without the intervention of other external agents. An example of this is the physiological stress response which characteristically involves the complex interaction of neural, hormonal, and metabolic reactions.

Second, behavior influences health through harmful living habits and activities. Cigarette smoking is probably the most well known behavior in this category, having been implicated as a risk factor for the three leading causes of death in the United States—coronary heart disease, cancer, and stroke. Poor diet, lack of exercise, excessive alcohol consumption, and poor personal hygiene are also linked to disease. Because many of these habits are influenced by the social environment and the individual's response to it, research has focused on the role of lifestyles and social patterns in the development of chronic diseases, and on various individual and public health approaches to prevent or modify these harmful behaviors.

A third means by which behavior affects physical health is in the response to symptoms and in patients' reactions to the sick role. For example, there has been a great deal of research on social and psychological influences on patients' reactions to pain and illness, and their decisions to seek medical care (e.g., many patients deny symptoms and/or postpone seeking help). Another example of such harmful behavior is noncompliance with medical prescriptions and physicians' advice, thus limiting the success of medical treatment.

The first portion of this essay examines research on the role of behavorial processes in the development and course of physical illness. Emphasis is given to coronary heart disease and high blood pressure, since particular progress has been made with these disorders. Two promising psychosocial risk factors for coronary heart disease are psychological stress, and the Type A behavior pattern, which consists of excessive competitive drive, impatience, and hostility. Both stress and Type A behavior are thought to influence the disease process by activating cardiovascular and humoral mechanisms. Research also suggests that genetic predispositions to high blood pressure may relate to over-response of the cardiovascular system to situations that involve coping with the environment. Other evidence suggests that behavioral factors may contribute to the development of infectious diseases, psychosomatic disorders (e.g., peptic ulcer), and human cancers. A new and promising research area, psychoneuroimmunology, has established interrelationships among the central nervous system, endrocrine, behavioral and immunological responses.

Effective behavioral techniques are now being used in treatment and rehabilitation and for psychosomatic disorders, pediatric and geriatric problems, and the treatment of chronic pain. Progress has been made in understanding and controlling pain, and a new interest in particular mechanisms of pain relief (e.g., the role of endorphins) is developing. The problem of noncompliance with treatment prescriptions is also being addressed by current research. Furthermore the smoking problem has been given considerable attention. Promising work has been done to prevent smoking in adolescents, and both individual therapies and media-based techniques have been used to modify the smoking habit.

The public policy implications of research on behavior and health include increased recognition of the importance of social and behavioral processes by practitioners, health-care policy planners, and the biomedical research community. Since many of the major health problems have their roots in individual behaviors, humane and effective prevention and treatment approaches must be based on the body of data derived from study of behavior and health. Research frontiers which explore mechanisms integrating social, behavioral, and biomedical processes must be fostered, and continued scientific progress requires that investigators be trained to integrate the research skills of these respective disciplines.

Promising research areas in the field of behavior and health include the study of psychosocial stress and mechanisms linking and/or preventing stress and illness; psychoneuroimmunology; techniques for enhancing medical compliance; and the challenge of preventing and permanently modifying health-impairing habits. Large-scale trials examining the effects of altering health-impairing habits on cardiovascular disease morbidity and mortality are currently under way. However, further biobehavioral research to elucidate underlying mechanisms linking behavior and health must accompany these preliminary efforts at intervention. The identification of appropriate targets for change and the development of effective intervention techniques must rely on a more complete understanding of these processes.

INTRODUCTION

The social and behavioral sciences have become increasingly significant for problems of physical health. These disciplines have matured and expanded beyond the one area of mental health to a far broader area called "behavioral medicine," which is concerned with behavioral factors in physical disease. At the same time, old disciplinary boundaries are being erased; behavioral and biomedical scientists alike are studying the joint influence of psychosocial and biological factors on somatic health and illness.

Disease has been viewed by Western medicine as a biological phenomenon, that is, a product of specific agents or pathogens and bodily dysfunction. However, this biomedical model has not accounted for all illness states, nor has it explained selective susceptibility and the fact that certain diseases occur in some people but not in others. The need for a broader model of health and illness, encompassing psychological and social variables and their interaction with biological processes, has been jointly recognized by the biomedical community (Engel, 1977) and by behavioral scientists (e.g., Miller, 1976; Matarazzo, 1980). Many medical problems, including some of the most common in modern society (e.g., heart disease, cancer), appear to be influenced by behavioral and social variables such as habits of living (e.g., smoking, diet, exercise), or by what has been termed psychosocial stress. For example, epidemiologists studying lung cancer have considered many causal variables, including heredity and the physical environment (particularly air pollution), but the strongest risk factor turns out to be a behavioral variable, namely, cigarette smoking.

In the United States at the turn of the century, the greatest contributors to morbidity and mortality were the infectious diseases. Today, the leading causes of mortality are chronic diseases, including the cardiovascular disorders and cancer. These disease states are caused by a confluence of social, environmental, behavioral, and biological factors (Institute of Medicine, 1978; U.S.D.H.E.W., 1979a). The crucial role of behavioral variables in today's most pressing health problems is clearly stated in the 1979 Surgeon General's Report on Health Promotion and Disease Prevention: ". . . of the ten leading causes of death in the United States, at least seven could be substantially reduced if persons at risk improved just five habits: diet, smoking, lack of exercise, alcohol abuse, and use of antihypertensive medication" (p. 14).

In recent years, important associations between psychosocial variables and physical disease outcomes have been documented. A biobehavioral paradigm has emerged from this work in an effort to advance scientific understanding beyond the descriptive level. In contrast to a purely correlational approach, biobehavioral research explores basic mechanisms linking behavioral processes to disease states. This research involves integration of behavioral science principles and methods with biomedical knowledge of the disease being studied. An example is provided by recent evidence linking psychosocial factors (e.g., emotional stress) to the development of cardiovascular disease. Behavioral scientists working in this area are devoting increasing attention to physiological processes (e.g., neuroendocrine activity) implicated in the development of coronary heart disease in order to determine how these processes are influenced by behavioral events.

MECHANISMS INVOLVED

The processes linking behavior to physical illness of various kinds may be grouped into three broad categories, as outlined on the following pages.

Direct Psychophysiological Effects

The first category involves alterations in tissue function via neuroendocrine and other physiological responses to psychosocial stimuli. This mechanism encompasses bodily changes without the intervention of external agents such as cigarette smoking or dietary risk factors, although the two sets of variables may produce interactive effects (e.g., stress and smoking might increase, synergistically, the risk of coronary heart disease).

Central to this process is the concept of stress, which was originally described by Hans Selye (1956) as a nonspecific response of the body to external demands that are placed upon it. According to Selye, the stress response proceeds in a characteristic three-stage pattern which involves a variety of physiological systems (neural, hormonal, and metabolic) in complex interrelation with each other. The term "stress" is also used in a psychological sense (Cox, 1978; Lazarus, 1966) to refer to an internal state of the individual who is perceiving threats to physical and/or psychic well-being. This broader use of the term places emphasis on the organism's perception and evaluation of potentially harmful stimuli, and considers the perception of threat to arise from a comparison between the demands imposed upon the individual and his felt ability to cope with these demands. A perceived imbalance in this mechanism gives rise to the experience of stress and to the stress response, which may be physiological and/or behavioral in nature.

Physiological responses to stress include neural and endocrine activity, which, in turn, can influence a wide range of bodily processes including metabolic rate, cardiovascular and autonomic nervous system functioning, and altered immune reactions (Levi, 1979; Mason, 1971). Short-term stress responses include hormonal and cardiovascular reactions (e.g., increased heart-rate, blood pressure), which may precipitate clinical disorders (e.g., stroke, cardiac instabilities and pain syndromes, psychosomatic symptoms, etc.) in predisposed individuals. If stimulation becomes pronounced, prolonged, or repetitive, the result may be chronic dysfunction in one or more systems (e.g., gastrointestinal, cardiovascular, etc.).

Early stress research (Selye, 1956) emphasized the generality or nonspecificity of responses to a wide variety of stimuli, but subsequent work has recognized that the link between stress and disease is not simple; instead, it depends upon the context in which the stressful agent occurs, how individuals appraise it, and the social supports and personal resources available (Lazarus, 1966; F. Cohen et al., 1981; Mason, 1971). There are wide individual differences in physiological responses to stressors, which depend not only on biological predispositions (Levi, 1979), but also on the individual's felt ability to cope with or master conditions of harm, threat, or challenge. For example, stressful events (e.g., failure, loss of loved ones, divorce, etc.) are inevitable throughout the life cycle, yet only a minority of individuals suffer lasting adverse effects. Research has shown that a variety of social and psychological factors (e.g., styles of coping; social supports provided by others) act to modify or buffer the impact of stressful events on illness (Cohen et al., 1981).

It should be emphasized that since the processes in this category involve functional alterations brought about, in part, by exposure to psychosocial stimuli, adequate scientific understanding requires a specification of mediating physiological processes (e.g., sympathetic-adrenomedullary and pituitary-adrenocortical axes). It is not enough to establish correlations between disease endpoints and behavioral variables.

Health-Impairing Habits and Lifestyles

A second means by which behavior leads to physical illness occurs when individuals engage in habits and styles of life that are damaging to health. Personal habits play a critical role in the development of many serious diseases, as amply documented by the recent Surgeon General's reports on smoking and health, and health promotion and disease prevention. Cigarette smoking is probably the most salient behavior in this category, for it has been implicated as a risk factor for three leading causes of death in the United States—coronary heart disease, cancer, and stroke. However, poor diet, lack of exercise, excessive alcohol consumption, and poor hygienic practices also have been linked to disease outcomes. These habits may be deeply rooted in cultural practices or initiated by social influences (e.g., smoking to obtain peer group approval). They may be maintained as part of an achievement-oriented lifestyle, as well as by the interaction of biological and behavioral mechanisms of addiction. Therefore, a major focus of behavioral medicine research has been on the role of sociocultural systems, lifestyles, and psychophysiological processes in the etiology and pathogenesis of the chronic diseases. Considerable attention also has been directed toward the development of techniques to modify those behaviors that constitute risk factors for illnesses.

Reactions to Illness and the Sick Role

A third process through which behavior leads to physical illness occurs when individuals minimize the significance of symptoms, delay in seeking medical care, or fail to comply with treatment and rehabilitation regimens. One prominent example is the sizable number of heart attack patients who procrastinate in seeking help, thereby endangering their chances of survival. These actions are representative of a large area of study concerned with the way people react to the experience of organ dysfunction (illness behavior), as well as to the experience of being in the role of a sick person (patienthood). To succeed, medical therapies require that the patient follow the physician's advice, but an extensive literature reports disturbingly low rates of compliance with health and medical care regimens (Sackett and Haynes, 1976). Accordingly, there has been considerable research on social and psychological processes involved in patients' reactions to pain and illness, the decision to seek medical care, and medical compliance. This research has led to the development of interventions that have been applied in treatment and rehabilitation settings.

OVERVIEW

The categories outlined above direct attention to the range of behavioral variables, acknowledged as important factors in somatic health and illness. Traditionally, biomedical and behavioral scientists have studied many of these same problems independently of one another and from different perspectives. In recent years, there has been more interdisciplinary contact along with a growing audience for complex problems of behavior and health.

In a paper of this length, it is impossible to represent fully the broad spectrum of health-related behavioral research. Therefore, this essay will not attempt to discuss mental illness categories or substance abuse disorders, except insofar as they are related to physical disease endpoints (e.g., cigarette smoking leading to cancer and heart disease). Instead, we will consider first the literature on behavioral and social factors in the etiology and pathogenesis of selected physical diseases such as cancer, psychosomatic disorders (e.g., ulcers), and infectious disease. Because considerable progress has been made in understanding the relationship between behavior and the major cardiovascular disorders (the leading cause of death in the United States), emphasis will be directed to this area as an exemplar of the biobehavioral approach to physical illness. Next, consideration will be given to treatment, rehabilitation, and prevention of physical disease. This discussion will not be limited to any one disorder but, instead, will emphasize themes that have relevance to a variety of somatic illnesses. We will conclude with an overview of research directions projected for the next five years.

BEHAVIORAL FACTORS IN THE ETIOLOGY AND PATHOGENESIS OF PHYSICAL DISEASE

In 1900, the leading causes of death in the United States were pneumonia, influenza, and tuberculosis. Changing patterns of illness since that time have been marked by the ascendancy of cardiovascular disease as the chief cause of mortality in this country. The cardiovascular disorders, including coronary heart disease and high blood pressure, now account for more than half of all deaths. A large percentage of these would be classified as "premature," for they occur during the middle years of 35 to 50 (National Science Foundation, 1980).

ATHEROSCLEROSIS, CORONARY HEART DISEASE, AND SUDDEN DEATH

Coronary atherosclerosis is a symptomless condition characterized by narrowing and deterioration of the arteries, including the coronary arteries, that is, blood vessels that nourish the heart. An excess accumulation of cholesterol and related lipids forms a mound of tissue, or atherosclerotic plaque, on the inner wall of one or more of the coronary arteries (Hurst et al., 1978). The formation of atherosclerotic plaques may proceed undetected for years, affecting cardiac functioning only when they cause a degree of obstruction sufficient to diminish blood supply to the heart. Once this occurs, coronary atherosclerosis has evolved into coronary heart disease (CHD).

In one form of CHD, angina pectoris, occasional instances of inadequate blood supply (ischemia) cause the individual to experience attacks of chest pain. Although ischemia *per se* does not cause permanent tissue damage, angina is a painful condition that can lead to more serious complications. A more severe and frequent fatal consequence of CHD is myocardial infarction (MI), or heart attack, in which a prolonged state of ischemia results in death of a portion of the heart tissue. Other manifestations of CHD include congestive heart failure, conditions secondary to MI (e.g., ventricular failure, heart rupture), and disturbances of the conductive or beat-regulating portion of the heart, i.e., the arrhythmias (Hurst et al., 1978).

Standard Risk Factors for Cardiovascular Disease

Individuals who are likely to develop coronary heart disease may be identified with a modest degree of accuracy. This is possible because a set of "risk factors" has been recognized in recent years. A CHD risk factor is an attribute of the population of interest, or of the environment, which appears to increase the likelihood of developing one or more of the clinical manifestations of cardiovascular disease. The following risk factors have been identified: (1) aging; (2) sex (being male); (3) elevated serum cholesterol and related low-density lipoproteins; (4) dietary intake of animal fats and cholesterol; (5) high blood pressure; (6) heavy cigarette smoking; (7) diabetes mellitus; (8) specific diseases such as hypothyroidism; (9) family history of coronary disease; (10) obesity; (11) sedentary lifestyle; and (12) specific anomalies of the electrocardiogram, such as evidence of left ventricular hypertrophy (Kannel et al., 1976).

It should be emphasized that the predictive value of these variables is, in most cases, far from being a settled issue. For example, the pathogenic influence of a sedentary lifestyle and obesity *per se* failed to receive empirical support in a number of investigations (Mann, 1974). Early emphasis placed upon the role of dietary fat intake has also been challenged in recent years (Mann, 1977). Suffice it to say here that coronary disease has a multifaceted etiology that involves many of the factors listed above in varying degrees of importance.

The risk-enhancing effects of the standard risk factors have been viewed in terms of their physiological influence (e.g., toxic effects of tars and nicotine; the role of salt intake in regulating blood pressure levels; the relationship between diet and serum cholesterol). Note, however, that many of these variables are determined, at least partially, by behavioral factors. For example, cigarette smoking is a preventable behavior undoubtedly brought about by psychosocial forces (Leventhal and Cleary, 1980). Cultural, racial, and social class groups differ in serum cholesterol levels, independently of dietary practices (McDonough et al., 1965). Enhanced risk due to sex and age may also derive from non-biological correlates of these variables, such as occupational pressure, stressful life events, and behavior patterns (Eisdorfer and Wilkie, 1977; Riley and Hamburg, 1981).

Resting blood pressure levels differ between racial groups, socioeconomic status, and cultures (Weiner, 1977). Family history of coronary disease, while in some cases linked to a specific genetic mechanism (e.g., Goldstein and Brown, 1974), may also lead to enhanced risk of CHD through psychosocial channels such as family patterns of cigarette smoking, diet, and socioeconomic condition. At least two implications follow from these observations: (1) analysis of the etiology and pathogenesis of coronary disease must be extended into the domain of psychosocial factors; and (2) psychosocial factors should be considered important targets in the prevention and treatment of CHD.

Psychosocial Risk Factors for Coronary Disease

The best combinations of the standard risk factors fail to identify most new cases of heart disease (Jenkins, 1971). Some variable or set of variables appears to be missing from the predictive equation. This limitation in knowledge has led to a broadened search for influences and mechanisms contributing to coronary risk; it now includes social indicators such as socioeconomic status and social mobility, and psychological factors such as anxiety and neuroticism, psychological stress, and overt patterns of behavior. The results have been encouraging, though not uniformly so. The two most promising psychosocial risk factors to emerge in recent years are psychological stress and the Type A coronary-prone behavior pattern (Jenkins, 1971).

Psychological Stress As noted earlier, Selye (1956) first popularized the notion of stress, which he defined as the body's non-specific physiological reaction to noxious agents or stressors. More recently, psychological investigators such as Lazarus (1966) and Mason (1971) have taken exception to this view, arguing that the body's response varies with the particular type of stressor and the context in which the stressor occurs (Lazarus, 1966; Glass and Singer, 1972).

Several indices of psychological stress have been studied in relation to the development of coronary disease. Research suggests that excessive work and job responsibility may enhance coronary risk, especially when they approach the limits of the individual's capacity to control his work environment (Haynes et al., 1980; House, 1975). Another job-related stressor that appears to be related to coronary disease is reported work dissatisfaction, such as lack of recognition by superiors, poor relations with co-workers, and inferior work conditions (House, 1975). Other life dissatisfactions, including problems and conflicts in areas of finance and family, have been correlated with the presence and future development of coronary disease (Haynes et al., 1980; Medalie et al., 1973).

The experience of a single, traumatic life event has long been suspected as a cause of clinical CHD (e.g., Cannon, 1942). More recently, it has been suggested that the cumulative effects of repeated adjustments required by life changes drain the adaptive resources of the individual and increase susceptibility to a variety of diseases. To test this, an objective instrument, the Social Readjustment Rating Scale (SRRS), was developed by Holmes and Rahe to assess the impact of such events as the death of spouse, a change to a different line of work, and a son or daughter leaving home (Holmes and Rahe, 1967).

Several retrospective studies have used this technique in an effort to link the accumulation of life events with the occurrence of coronary disease (cf. Garrity and Marx, 1979). For example, survivors of myocardial infarction show a pattern of increased life changes during the period approximately one and one-half years before the MI, whereas healthy control subjects reported a relatively stable number of life events during the same period. Other research, in which information regarding life events prior to sudden cardiac death was obtained from a survivor of the deceased (usually the spouse), revealed an accumulation in the intensity of life events in the 6 months prior to death (Garrity and Marx, 1979).

Despite replication of the foregoing findings, negative results have been reported as well (e.g., Hinkle, 1974). Reviewers point to defects in the methodology of retrospective designs that might account for the positive findings (Dohrenwend and Dohrenwend, 1978). However, such explanations cannot explain significant associations obtained in prospective studies in which data concerning psychosocial stressors were obtained prior to the development of disease (e.g., Haynes et al., 1980; Medalie et al., 1973).

The relation of stress to pathological outcomes depends upon both the adaptive capacity of the individual before the stressor occurs and the resources marshaled in response to its occurrence (Cohen et al., 1981). It follows that variables moderating the impact of stress must be taken into account in order to gauge the predictive validity of stress as a risk factor for coronary disease. These moderators include biological factors (e.g., genetic susceptibility, general state of health); psychological attributes (e.g., felt ability to cope); aspects of the immediate context in which the stressor occurs (e.g., whether the stressor is perceived as controllable); various sociocultural variables (e.g., amount of social support from other people and/or the health care system); and factors related to the life course (e.g., the expectedness of events at a certain stage of life). For example, there is evidence that individuals who have social supports may live longer, have a lower incidence of somatic illness, and possess higher morale and more positive mental health (Cohen et al., 1981).

Type A Coronary-Prone Behavior Pattern Perhaps the most thoroughly investigated psychosocial risk factor for coronary disease is the Type A behavior pattern (Rosenman and Friedman, 1974). Type A (or Pattern A) is characterized by extreme competitiveness and achievement striving, a strong sense of time urgency and impatience, hostility, and aggressiveness. The relative absence of these traits is designated as Type B.

The Type A concept does not refer simply to the conditions that elicit Pattern A behavior, nor to the responses *per se*, nor to some hypothetical personality trait that produces them. It refers, instead, to a set of behaviors that occur in susceptible individuals under appropriately stressful and/or challenging conditions. Pattern A is, therefore, the outcome of a person-situation interaction. It is not a typology, but a behavior *pattern*, which is displayed in varying degrees, at one time or another, by everyone.

People who consistently display Type A characteristics have long been suspected of being at greater risk for clinical CHD (Osler, 1892). However, the major impetus for research validating this hypothesis comes from work initiated by cardiologists Meyer Friedman and Ray Rosenman only two decades ago. These investigators developed a structured interview (SI) which constitutes the major tool for the diagnosis of Pattern A. More recently, two self-administered questionnaires have been developed to detect Type A behavior.

Although several studies have documented an association between Pattern A and CHD, the most convincing evidence comes from the WCGS, or Western Collaborative Group Study (Rosenman et al., 1975). In this prospective, double-blind study, more than 3,000 initially healthy men, 39 to 59 years of age, were assessed for a comprehensive array of social, dietary, biochemical, clinical, and behavioral variables. An eight and one-half year follow-up showed that subjects exhibiting Type A behavior at the study's inception were about twice as likely as Type B individuals to develop coronary heart disease (i.e., angina pectoris or myocardial infarction). This two-fold differential in risk remained when statistical procedures were used to control for the influence of other risk factors such as cigarette smoking, serum cholesterol, and high blood pressure. This research also has linked Pattern A to sudden cardiac death (Friedman et al., 1973) and recurrent MI.

An eight-year follow-up of data from the Framingham Study, a large-scale prospective study of heart disease undertaken by the National Institutes of Health, indicated that Pattern A is predictive of CHD in both men and women, although for male subjects the enhanced risk appeared only among white-collar workers (Haynes et al., 1980). After controlling for the influence of the traditional risk factors, it was found again that Pattern A conferred increased CHD risk. The prospective association of Pattern A with coronary disease in the WCGS and the Framingham Study constitutes strong evidence for the independent pathogenic influence of the behavior pattern.

There may be an association between Pattern A and coronary atherosclerosis. Supporting evidence has been obtained through the use of coronary angiographic techniques that make it possible to quantify the extent of coronary artery disease in living patients (e.g., Blumenthal et al., 1978). In a recent study of men who underwent repeated coronary angiograms, an association was found between Pattern A and the progression of atherosclerosis (Krantz et al., 1979). It should be noted, however, that evidence for the association between Pattern A and coronary atherosclerosis is not unequivocal (Dimsdale et al., 1980).

Pathophysiological Mechanisms Linking Stress and Behavior Pattern A to Coronary Disease It is not enough to demonstrate a relationship between CHD risk factors—whether biomedical or psychosocial in nature—and the occurrence of cardiovascular disease. The precise mechanisms mediating the association must be specified. Although the pathogenesis of coronary disease is not completely understood, several factors are believed to play a major contributing role. These include a variety of physiological and biochemical states which may enhance coronary risk by influencing the initiation and progression of atherosclerosis and/or by precipitating clinical CHD (Herd, 1978; Ross and Glomset, 1976). Many of these physiological states have been observed in experimental studies of psychological stress. For example, hemodynamic effects such as elevated heart rate and blood pressure, and biochemical changes such as increased levels of serum cholesterol, are produced in animals under prolonged or severe stress (Schneiderman, 1978). It has been observed, in addition, that a reduction in blood-clotting time occurs under conditions of stress and, in some cases, degeneration of heart tissue has been reported as well. Other animal research has linked laboratory stressors to a lowered threshold for ventricular arrhythmia and for ventricular fibrillation (e.g., Lown et al., 1973), a state which leads to sudden cardiac death unless immediate treatment is given.

Potentially pathogenic states also have been observed in studies of psychological stress in healthy humans. For example, life stressors such as occupational pressure have been shown to produce biochemical changes such as elevated levels of serum cholesterol (Friedman et al., 1958). Other research has demonstrated an association of increased heart rate and blood pressure with stressors such as the performance of mental arithmetic, harassment, and threat of electric shock. Still other studies report that the stresses of automobile driving, public speaking, and discussion of emotionally-charged topics provoke ventricular arrhythmia (Herd, 1978).

A notable feature of the foregoing research is the measurement of physiological reactivity in response to stress, as distinct from the observation of basal or resting levels of physiological variables. These changes in functioning, which are not detected by basal risk-factor measurement, are believed to yield a better index of the pathogenic processes involved in coronary disease. In addition, by observing such changes in response to real-life or laboratory-induced stressors, pathogenic states may be detected within the context of their psychosocial antecedents.

The physiological concomitants of psychological stress are believed to result from activation of tHe sympathetic-adrenal medullary system (SAM) and the pituitary-adrenocortical axis (PAC). Interest in the impact of SAM activation on bodily reactions to emergency situations may be traced to Walter Cannon's work on the fight or flight response. This neuroendocrine response appears to be elicited in situations demanding effortful coping with threatening stimuli (Frankenhaeuser, 1971). The hormonal responses of the PAC axis were emphasized by Selye in his notion of a generalized physiological response to aversive stimulation. The PAC secretions include a number of hormones that influence bodily systems of relevance to the development of coronary disease. The corticosteroids, which include cortisol, regulate the metabolism of cholesterol and other lipids involved in the atherosclerotic process. Activation of the SAM system also may have a special significance in mediating stress-related pathophysiological changes. Particularly culpable in this regard is secretion of the catecholamines, epinephrine and norepinephrine, which are believed to induce many of the pathogenic states associated with psychological stress. These include increased blood pressure and heart rate, elevation of blood lipids, acceleration of the rate of damage to the inner layers of the coronary arteries over time, and provocation of ventricular arrhythmias, believed to lead to sudden death.

The same pathophysiological mechanisms linking stress and coronary disease may apply, *a fortiori*, to Type A individuals, thereby accounting, in part, for their enhanced coronary risk. Research has shown greater urinary catecholamine secretion during the working day and greater plasma catecholamine responses to competition and stress among Type A's compared to Type B's (Rosenman and Friedman, 1974). Recent studies by Glass et al. (1980) also have demonstrated higher elevations in plasma catecholamines among Type A individuals in situations of hostile competition. Subjects were led to believe they would compete for a prize with an opponent (who was actually an experimental confederate) on a challenging electronic game. A and B subjects were exposed to one of two experimental conditions. In the *No Harass* condition, the confederate remained silent and simply competed against the subject. In the *Harass* condition, the same procedure was followed with one variation: the confederate made a series of preprogrammed remarks designed to harass the subject. Throughout the task, blood pressure and heart-rate were measured and blood samples were drawn via an in-dwelling venous catheter. Results showed that harassment had an effect on plasma catecholamines, blood pressure, and heart rate for both types of subjects. However, of those harassed, Type A's showed increased elevations of plasma epinephrine, systolic blood pressure and heart rate. These cardiovascular and neuroendocrine changes are consistent with the findings of other investigators indicating greater cardiovascular reactivity among A's than B's in challenging situations (Dembroski et al. 1978; Herd, 1978).

HIGH BLOOD PRESSURE

High blood pressure (also called essential hypertension) is a condition of unclear etiology in which blood pressure shows chronic elevations. When the disorder becomes developed fully, increased pressure is usually due to a constriction or contraction of blood vessels throughout the body (Page and McCubbin, 1966). Although high blood pressure (HBP) is a symptomless disorder, there is epidemiologic evidence that even mild blood pressure elevations are associated with a shortening of life expectancy (Kannel and Dawber, 1971), and increased risk of coronary heart disease and stroke. As is the case with CHD, the causes of HBP are believed to involve complex interactions among genetic, socio-cultural, behavioral, and physiological processes.

Heterogeneity of the Disorder and Physiological Mechanisms

Essential hypertension is not a single, homogeneous disease. In the development of the disorder, blood pressure is thought to progress over a period of years from moderately elevated or "borderline" levels to more appreciably elevated levels, called "established" hypertension. Several pathogenic mechanisms may bring about blood pressure elevations, and different physiological and/or behavioral mechanisms are implicated at various stages of the disorder. For example, individuals with borderline hypertension are commonly observed to have an elevated cardiac output (i.e., amount of blood pumped by the heart) but little evidence of increased resistance to the flow of blood in the body's vasculature (Julius and Esler, 1975). As noted earlier, this physiological pattern is consistent with increased activation of the sympathetic nervous system, which is the body's initial reaction to psychological stress. However, in older individuals with more established high blood pressure, cardiac output is either normal or depressed, while the vascular resistance is elevated. Although psychological stimuli such as emotionally stressful events have been shown to correlate highly with the exacerbation of hypertensive episodes in diagnosed patients (cf. Weiner, 1977), recent research on behavioral influences has focused increasingly on earlier stages, rather than on the culmination of the disease.

In addition to cardiovascular adjustments and changes, the physiological mechanisms of high blood pressure probably involve the interaction of the central and autonomic nervous systems, the endocrine-hormonal system, and the kidneys. Accordingly, behavioral factors (in particular, psychological stress), might play a role in the etiology of HBP via a number of physiological pathways (Kaplan, 1980). Recall that stress leads to discharge of the sympathetic nervous system and to increases in catecholamines. High levels of blood and tissue catecholamines have been found in some hypertensive humans and animals (Julius and Esler, 1975). Such elevations could lead to increased blood pressure via increased heart rate and force of heart action, constriction of peripheral blood vessels, and/or activation of a hormonal mechanism in the kidney that constricts the vasculature (Kaplan, 1980) and regulates the volume of blood (see below). It should be noted that the cardiovascular system has an intrinsic means of regulating blood flow, namely the constriction of blood vessels whenever blood flow is increased (autoregulation). Elevated output of blood from the heart produced by nervous system activity might also lead to pressure elevations via this mechanism.

There has been much investigation of the role of the kidney in hypertension. The enzyme, renin, which is released by the kidney, is involved in a physiological regulatory process (the renin-angiotensin-aldosterone mechanism), which leads the kidney to increase water reabsorption and expand the volume of blood, thus raising the pressure (Kaplan, 1980). The process of renin release normally should be dampened whenever the blood pressure is raised, but in a subcategory of individuals with HBP, level of renin in the blood is inappropriately high. Thus, presumably, both with or without the involvement of the sympathetic nervous system, the renin-angiotensin system is an important mechanism in etiology and maintenance of high blood pressure.

Genetic-Environment Interactions

The prevalence of essential hypertension in the U.S. usually increases with age, and below the age of 50 years it occurs with less frequency in women than in men (Weiner, 1977). Evidence from animal research and studies of human twins indicates that genetic factors play a role in the etiology of the disease (Pickering, 1967). This evidence suggests that many genes are involved in the susceptibility to HBP, and it is likely that in humans, sustained elevations in blood pressure are produced by an interaction of a variety of environmental and genetic factors. Consider that epidemiological studies reveal a difference in the prevalence of HBP among various social and cultural groups, a difference which cannot be accounted for by genetic factors alone (Henry and Cassel, 1969). For example, in the United States, hypertension is more common among blacks than among whites, but the prevalence of high blood pressure is greater in poor than in middle class black Americans (Harburg et al., 1973). Animal research, described below, similarly reveals examples where environmental factors (such as dietary salt intake or environmental stress) lead to sustained blood pressure elevations only in certain genetic strains. Closely related to this observation is the finding that family members tend to have similar blood pressures. Although the prevalent view attributes this solely to a genetic source, there is emerging evidence suggesting joint genetic and environmental effects. A possible environmentally-determined behavioral factor, family social interaction, is illustrated by a recent study which observed more negative nonverbal behavior (e.g., grimacing, gaze aversion) among families with a hypertensive father, compared to families with a normotensive father (Baer et al., 1980).

Behavioral Factors

Sociocultural and psychological studies of humans, in conjunction with animal research, have identified some environmental factors related to behavior that might play a role in the initiation of HBP. These factors include dietary intake of salt, obesity, and psychological stress.

Dietary Salt Intake Much has been written about the role of salt in essential hypertension, largely because excessive intake of sodium is thought to increase the volume of blood. However, studies indicate that high salt intake may be associated with high blood pressure levels only in some cultures and population groups. The relationship between salt intake and HBP appears to be complex, and salt intake may result in sustained blood pressure elevations only in genetically predisposed individuals. For example, Dahl and co-workers (Dahl et al., 1962) found that there are salt-sensitive and salt-resistant strains of rats; more recently, studies of increased sodium intake in humans have noted that mild hypertensive patients can be divided into groups that are differentially sensitive to increased salt intake (Kawasaki et al., 1978).

Research also suggests that reduction in sodium intake can result in decreased blood pressure (Shapiro, forthcoming). Evidence that decreasing sodium intake in the diet will lower blood pressure in humans derives from several sources: from studies showing the effectiveness of diuretic (sodium and fluid excreting) medication; from studies demonstrating that drastic sodium restriction can measurably lower blood pressure (cf., Shapiro, forthcoming); and, conversely, from studies indicating that healthy persons put on high sodium diets show pressure increases. At present we do not fully understand the human craving for salt intake in excess of physiological needs, but evidence suggests that it may, in part, be a habit that is learned.

Obesity Obesity is another cultural and behavioral phenomenon that plays an important role in hypertension, although the precise reasons for the higher prevalence of high blood pressure in obese patients have not been determined. In the case of obesity, recent studies have determined that weight loss can result in significant decreases in blood pressure (cf. Shapiro, forthcoming). As is the case with all non-pharmacologic approaches involving lifestyle alterations, effective treatment outcomes depend not only on producing transitory changes in behavior, but also on the maintenance of these changes and sustained compliance with prescribed regimens. We will discuss these issues more fully in a later section of this chapter.

Psychosocial Stress Stress deriving from psychosocial causes is yet another factor implicated in the etiology and maintenance of high blood pressure. As previously described, psychological stimuli that threaten the organism result in cardiovascular and endocrine responses that can play an important role in the development of hypertension (Julius and Esler, 1975). The brain and central nervous system, which are involved in determining whether situations are harmful or threatening, thus play a role in physiological mechanisms mediating the impact of noxious stimuli. On a societal level, there is some evidence that blood pressure elevations occur under conditions of rapid cultural changes and socio-economic mobility. Moreover, there are many studies in which "primitive" populations living in small cohesive societies were found to have low blood pressure that did *not* increase with age. When members of such societies migrated to areas where they were suddenly exposed to Western culture, they were found to have high levels of blood pressure that increased with age. This suggested some cumulative effect of the new living conditions that became evident over the course of the life span (Henry and Cassel, 1969).

Whereas such studies can attempt to rule out confounding factors, (e.g., diet, sanitation, etc.) by using carefully matched control groups and by employing statistical control techniques, there are inherent limits to conclusions that can be reached from correlational research. Experimental techniques for inducing HBP in animals offer the ability to control both genetic and environmental factors by manipulating separate variables relevant to the course of this disorder (Campbell and Henry, forthcoming). Accordingly, various animal models of experimental high blood pressure indicate that the brain participates at some stage or another in the development or maintenance of increased blood pressure levels. The role of stress in the etiology of hypertension is supported by experimental studies demonstrating that sustained and chronic blood pressure elevations can be produced in animals exposed to environmental events such as fear of shock, social isolation followed by crowding, and experimentally produced conflict (cf. Campbell and Henry, forthcoming). Studies have also shown that animals placed on learning schedules that reward them for conditions in which blood pressure remains elevated display sustained blood pressure elevations. Thus, there is the possibility that learning and conditioning processes might be involved in the development of the hypertensive state. In accord with our earlier discussion of genetic-environment interactions, studies have demonstrated that strains of animals that are genetically susceptible to hypertension are also susceptible to stress-induced pressure elevations. Dahl, Friedman and their co-workers (e.g., Friedman and Dahl, 1975) identified a genetic strain of rats that develops severe HBP if excess salt is ingested. While on a low salt diet these rats were subjected to an experimental treatment (called approach-avoidance conflict) which involved punishment for bar-pressing responses necessary to obtain food. Other rats of the same genetically-susceptible strain were yoked to these rats and received the same amount of food and shock but were *not* subjected to conflict; still others served as controls, receiving no shock but having free access to food. Results indicated that those rats exposed to the punished-eating conflict generally exhibited the highest mean blood pressures, followed by those given shock without conflict and also food deprived. Furthermore, in a related study Friedman and Iwai (1976) showed that a genetic strain not susceptible to salt-induced HBP did not develop pressure elevations when subjected to this same food-shock conflict situation.

Associations between emotional and behavioral stimuli and the development and/or maintenance of high blood pressure receive additional support from human studies indicating that techniques such as biofeedback and relaxation training can be used to modify the stress-induced components of high blood pressure (Shapiro, forthcoming). These techniques, to be discussed in more detail in a later section, are designed to counteract pressure-increasing stimuli that operate through the central and autonomic nervous systems.

Personality Correlates The traditional psychosomatic approach to HBP proposed that one's emotional dispositions or personality traits play a causal role in the development of chronic blood pressure elevations (Harrell, 1980). The individual susceptible to HBP has been described as one with inhibited and poorly expressed anger (supressed hostility), and it has been suggested that inhibited anger expresses itself in stimulation of the autonomic nervous system leading to acute and eventually chronic HBP. However, although emotional states such as anger do lead to cardiovascular adjustments resembling HBP, and although identifiable traits have been observed in patients with high blood pressure (Weiner, 1977), on balance, the search for a hypertensive personality has not yielded conclusive results. Patients with high blood pressure are not homogenous in terms of either physiological or psychological characteristics. A recent study showed convincingly that 30% of a sample of young male patients with HBP (namely, those with mild pressure elevations and high plasma renin levels) displayed *both* elevations in sympathetic nervous system activity and higher levels of suppressed hostility (Esler et al., 1977), a behavioral trait independently linked to increased nervous system activity. These results might be explained by suppressed hostility leading to blood pressure elevations, by increased nervous system activity as the initial event, or by some other underlying factor. This issue may be resolved with further studies of families of patients with HBP and the social interaction patterns that could have a bearing on the personality development of offspring, or with animal research which looks at behavioral characteristics associated with the development of high blood pressure in susceptible strains.

Behavioral-Cardiac Interactions

Experimental work has sought to identify individuals who are at risk of developing HBP, and the types of situations which might activate genetic predispositions to high blood pressure. Since the aim is to understand mechanisms in the *cause* of the disorder, research has focused increasingly on the beginning stage, rather than the culmination, of the disease.

Given that borderline high blood pressure is characterized by heightened responsiveness of the cardiovascular and sympathetic nervous systems to psychological stimuli such as mental stress (Julius and Esler, 1975), recent research has examined the tendency toward large episodic or acute increases in heart rate, blood pressure, and sympathetic nervous system hormonal (catecholamine) activity as possible mechanisms involved in etiology. Several groups of investigators (Manuck and Schaefer, 1978; Obrist, 1981), have found that cardiovascular responsiveness is a stable and persistently evoked response that can be measured reliably in a laboratory situation. Cardiovascular responsiveness to certain psychological stimuli has also been related consistently to family history of high blood pressure (a hypertension risk factor), even among individuals who have normal resting blood pressure levels and display no overt signs of the disorder (Obrist, 1981; Falkner et al., 1979). For example, in one representative study (Falkner et al., 1979), adolescents with normal blood pressure and at least one parent with HBP displayed greater diastolic blood pressure, heart-rate, and plasma catecholamine responses to a stressful mental arithmetic task compared to a control group of adolescents with no family history of HBP.

Obrist and his co-workers (Obrist, 1981) report that cardiovascular responsiveness above the level that is efficient for the body's metabolic needs results from situations where *active coping* or behavioral adjustments are required. In active coping situations, the organism tries to exert some behavioral control over a stimulus.

By contrast, sympathetically-mediated cardiovascular responses do not seem to be elicited in similar intensity or kind to other stressors (e.g., a stressful film), where the individual remains passive and does not take direct action to attempt to control the situation. This concept of active coping may underlie those psychosocial conditions (e.g., rapid cultural change, socioeconomic mobility) shown by epidemiologic research to be associated with blood pressure elevations in some human populations (e.g., Henry and Cassel, 1969).

By what physiological mechanisms might active coping and the resulting periodic increases in sympathetic nervous system activity lead to chronic blood pressure elevations? Research employing sophisticated pharmacological manipulations (such as the administration of drugs that selectively block the action of certain neurons) reveals that active coping with stress can alter regulatory mechanisms involving two physiological processes. In one, the heart pumps excessive amounts of blood, and in the other, the kidney reabsorbs excessive amounts of sodium with a resultant increase in the volume of blood (Obrist, 1981). In a series of animal studies, stress decreased water excretion to an extent exceeding the metabolic needs of the organism (Obrist, 1981), and exacerbated or precipitated high blood pressure in animals with impaired kidney function (Harrell, 1980). Studies of humans exposed to various stressors (e.g., Obrist, 1981), revealed that active coping is specifically associated with a pattern of cardiovascular response resulting in increased cardiac output. Further research employing selective blocking drugs with humans confirmed that these cardiovascular changes resulted from increased activity of the sympathetic nervous system.

In sum, these studies represent several approaches currently being used by social and behavioral scientists to understand the etiology of high blood pressure. They represent an attempt to move from the symptom-oriented and purely descriptive level to a focus on mechanisms. These early findings serve to justify further experimental, longitudinal, and naturalistic studies.

PSYCHOSOMATIC DISEASES: THE EXAMPLE OF PEPTIC ULCER

While there is evidence that a variety of physical disorders are, to some degree, caused or exacerbated by psychological or emotional factors, the terms "psychosomatic" or "psychophysiological" refer to those physical conditions that appear to be initiated primarily by psychological factors (American Psychiatric Association, 1968). It should be noted that these conditions involve actual organ pathology, often due to activity of the autonomic nervous system initiated by psychosocial stimuli. Common examples of physical conditions that may be subsumed under this category include, but are not limited to, tension and migraine headache, ulcer, asthma, and rheumatoid arthritis. We will discuss peptic ulcer as a representative disorder in this category.

A peptic ulcer is a lesion or sore in the lining of the stomach or the duodenum, the upper part of the small intestine that lies immediately below the stomach. A basic problem with the term "peptic ulcer" is imprecise definition, for it is used to include both gastric and duodenal ulcer. These two forms have certain common characteristics, but also significant differences. For example, duodenal ulcer is usually associated with an increase in gastric secretion of hydrochloric acid and the stomach enzyme, pepsin, whereas gastric ulcer is not necessarily characterized in this manner. Indeed, clinicians view gastric and duodenal ulcers as separate disorders, associated with different predisposing and initiating mechanisms (Weiner, 1977). Thus, the general term "peptic ulcer" can be misleading, for it is not one disease. Differences in anatomical location, natural history, pathophysiology, symptoms, and response to treatment produce considerable heterogeneity. Moreover, ulcers are sometimes "quiet" in the sense that they cause no discomfort, remaining unnoticed. Thus, the researcher investigating this disorder in symptomatic humans is not studying a population representative of all those who have the disease.

Physiological Mechanisms

Although new evidence about the physiological mechanisms involved in the pathogenesis of ulceration has developed in recent years, the disease processes are still poorly understood. It seems clear that the secretion of acid and pepsin by the stomach is important. Hydrochloric acid is continually being secreted into the stomach, even during sleep, and the secretion rate can be markedly increased by a variety of environmental stimuli, including smell, taste, sight, or even the thought of food (Weiner, 1977). Pepsin, produced in the stomach, is an important enzyme involved in the digestion of proteins. In about 50% of patients with active duodenal ulcer disease, elevated resting secretions of these two substances can be observed.

Release of pepsin and gastric acid are, at least in part, under the control of the central nervous system, particularly the vagus nerve which increases stomach motility and secretion. However, these substances are also under the complex control of a variety of other hormones produced in the stomach, pancreas, and kidney (Weiner, 1977). Both stimulation and destruction of selective sites of the brain can produce lesions of the stomach and/or duodenum (Brooks, 1967). There is little question that central neural processes can be critical in the regulation of gastric secretion and the production of some type of ulceration in both animals and humans. Whether or not these processes are active in the development of chronic ulceration in humans is less clear, largely because we lack biomedical knowledge of the precise physiology of ulcer disease.

Animal Research

Gastric lesions can be produced in animals by a wide range of manipulations, including restraint-immobilization, stressful conditioning techniques, and conflict situations, as well as food deprivation and painful sensory stimulation (Weiner, 1977). It should be noted that such lesions in animals are different in a number of ways from human ulcers, and therefore inferences to human disease from this work should be made with caution.

Studies with rats demonstrate that prior experience, particularly early in life, affects individual susceptibility to ulceration. For example, rats handled early in life were less likely to develop stomach lesions when immobilized than those who were not handled. However, rat pups separated prematurely from their mothers are more susceptible to gastric lesions (cf. Weiner, 1977). The age and genetic strain of an animal also affect its susceptibility to restraint-induced lesions. In addition, within a particular strain, susceptibility to ulcers seems to be related to individual variations in serum pepsinogen, a substance released under neural influences (Weiner, 1977) and converted to pepsin.

A series of experiments by Weiss (1972) employed behavioral techniques to demonstrate the role of psychological stress in the production of stomach lesions. These studies equated the strength, duration, and frequency of electric shock by using pairs of rats with electrodes on their tails wired together in series. One member of the pair was given a signal that enabled it to predict the onset of shock and determine when it was safe; the other animal received a signal at random. The animal able to predict shock occurrence developed considerably fewer stomach ulcers than the other animal. Furthermore, if the rat had available a simple coping response so that it could learn to control the shock, it developed fewer stomach lesions than its helpless partner who received exactly the same shocks without the ability to control them. By contrast, if the coping response involved conflict, so that the rat had to take a brief shock to escape a longer one, the results were reversed.

These studies demonstrate the role of psychological variables (e.g., controllability of shock, conflict), as distinguished from the physical intensity of noxious stimulation (held constant for all animals in the research), in the experimental production of lesions. Moreover, there was evidence in this research that individual differences in the animals' behavioral responses to unpredictable shock were related to lesion development. Under conditions of uncertainty, those animals that made many efforts to cope with noxious stimulation by actively trying to avoid shocks were most ulcer-prone.

Human Studies

Much of the research investigating the relationship between psychological variables and peptic ulcer disease in humans is confounded by methodological problems. These include uncertain diagnostic criteria, difficulties in psychophysiological measurement of gastrointestinal function, problems in selection of appropriate study populations (e.g., hospitalized vs. nonhospitalized patients, length of illness, etc.), and inappropriate control groups. Moreover, there have been few longitudinal studies in this area, so it is difficult to determine whether psychological variables preceded or followed illness. Nevertheless, there is evidence from human research that psychological factors (including stress) bear at least tentative relationships to the regulation of gastric secretion and to the initiation and/or precipitation of ulcer symptomatology.

Classic studies of patients with openings to the stomach (gastric fistulae) revealed a remarkable covariation between stomach secretions and a variety of emotional states such as anger, resentment, and depression (Wolf and Wolff, 1947). The traditional psychosomatic approach (Alexander, 1950) proposed that ulcer patients were characterized by a specific set of traits—namely, conflicts over dependency needs—which led to neural activation, and increased gastric secretions mediated by the vagus nerve. Evidence bearing on this hypothesis is inconsistent, but at least one prospective study of trainees for the military found that those who were hypersecretors of pepsinogen, an inherited risk factor for ulcers, could be identified on the basis of psychometric testing.

There have also been studies of individuals in stressful environments and occupations (Wolf et al., 1979). Recall that these situations are associated with cardiovascular disorders, including CHD and high blood pressure. Cobb and co-workers found that peptic ulcer was nearly twice as prevalent among air traffic controllers than among a matched control group in another occupation. In this study, the prevalence of ulcers was higher among workers in high stress, compared to lower stress control towers. In addition, there is evidence, which has been confirmed repeatedly, of a higher prevalence of peptic ulcer disease in men who have supervisory roles (i.e., foremen) as compared to executives and craftsmen (cf. Wolf et al., 1979).

Predispositions for Specific Disorders

The field of psychosomatic research has provided medicine with a basis for predicting who might be at risk for a specific illness, as well as knowledge of the conditions under which the predisposed individual is most likely to develop such a disorder. At one time, psychosomatics over-emphasized the role of individual differences or dispositions, without taking into account the physiological, genetic, and situational factors that interact in predisposing an individual to a particular illness (cf. Weiner, 1977). Today, this perspective has changed, and researchers have become aware of genetically and environmentally-determined physiologic response patterns that might predispose particular individuals to one disorder rather than another. (This is commonly referred to as the "specificity problem"). For example, studies have shown that individuals differ in secretion of pepsinogen, and also that the tendency to secrete this substance related to ulcer susceptibility may be genetically transmitted (Weiner, 1977).

It should be emphasized that a single predisposing factor may not be enough to result in physical disease. A variety of activating situations are necessary to produce organ dysfunction. This is amply demonstrated by studies of gene-environment interactions in the etiology of high blood pressure and ulcers; it is also shown by the importance of environmental challenge and/or stress in activating Type A behavior. Further investigation of factors leading to the expression of predispositions for specific disorders should contribute to basic knowledge concerning mechanisms of mind-body interaction and provide greater understanding of physiological disease processes.

CANCER

Cancer is the second leading cause of death in the United States, accounting for about 20% of the overall mortality rate, or nearly 400,000 deaths annually. Despite improvements in rate of cure, total cancer mortality has risen substantially over the past several decades. This may be attributable, in part, to the growing proportion of older people in the population, since the risk of developing cancer increases with age. Another reason for increased mortality is the dramatic rise in the incidence of lung cancer: cancer of the lung is the leading cause of death from cancer among men (U.S.D.H.E.W., 1979a; National Science Foundation, 1980), and may soon have a similar dubious distinction for women.

Cancers are not a single disease; instead, the term is used for more than 100 conditions characterized by unrestrained multiplication of cells and abnormal forms of cell growth (Fraumeni, 1975). One significant attribute of cancers is their ability to spread beyond the site of origin. They may invade neighboring tissue by direct extension, or disseminate to more remote locations through the blood stream or through the lymphatic system, which controls fluid transport between body tissues. It is believed that some or all cancers arise from a single abnormal or transformed cell, triggered in different ways to produce unrestrained multiplication (Levi, 1979). A complementary view is that cancer cells multiply and spread when a breakdown occurs in a portion of the immune system that performs the function of recognizing transformed cells and eliminating them before a detectable tumor can result.

The known risk factors for cancer include a variety of environmental agents, such as tobacco, X- and UV-radiation, alcohol, viruses, drugs, asbestos, and many chemicals. Personal attributes, including genetic predispositions, congenital defects, precancerous lesions, and aging, have also been implicated (Fraumeni, 1975). Tobacco is the exogenous substance for which data demonstrate a strong association with cancer: smoking increases the risk of lung cancer about 10-fold, increasing with duration of smoking and number of cigarettes smoked per day (U.S.D.H.E.W., 1979b). In addition, tobacco use enhances the effects of other carcinogens. For example, exposure to asbestos carries some risk to non-smokers; however, this is of a low order of magnitude compared to the risks experienced by cigarette smokers. It has been estimated that asbestos workers who smoked cigarettes had eight times the lung cancer risk of smokers without this occupational exposure (U.S.D.H.E.W., 1979a). This is 92 times the risk of non-smokers who did not work with asbestos.

While cigarette smoking represents a specific behavior with known pathogenic consequences, three other classes of psychological variables have been suspected as risk factors for cancer: (1) stressful life events, particularly those involving loss (e.g., bereavement); (2) lack of closeness to parents; and (3) inability to express emotions, especially negative ones (Fox, 1978; Schmale, 1981). The research designs used in most of these studies are retrospective. Various methodological flaws tend to render their results as suggestive only.

In a prospective study unique to this area, psychosocial data were obtained from 913 male medical students at the Johns Hopkins University long before the clinical appearance of disease (Thomas et al., 1979). A follow-up showed that 20 of the men developed cancer over the next 10 to 15 years. These men had reported a lack of closeness to parents on a Family Attitude Questionnaire taken at the inception of the study. Scores on this measure distinguished the future cancer victims from both the subjects who were to remain healthy and those who developed high blood pressure or myocardial infarction. However, even this study may be criticized for its statistical methodology. Many variables were measured and only a few yielded significant differences. Moreover, there was a failure to control for known cancer risk factors such as smoking. Replications of these findings are required before premorbid psychological characteristics can be accepted as risk factors for human cancers.

A related area holding some promise concerns the relationship of psychological factors to cancer growth and progression. This research is a subset of a larger area of study dealing with determinants of successful coping with chronic illness (e.g., Hamburg et al., 1980;

Krantz, 1980). Clinicians have often commented on the psychological differences between those cancer patients who do well or survive longer and those who do poorly or succumb rapidly to the disease. Characteristics such as low denial, depression, and anxiety have been related to poor cancer prognosis, and the experience of emotional stress has been observed in patients some months prior to relapse after long remission periods (cf. Miller and Spratt, 1979).

Research attempting to link psychosocial variables to cancer may be criticized for lacking a theoretical basis. Except for vague reference to the possibility that emotional stress may decrease bodily resistance to malignant growth, little attention has been given to the pathophysiological mechanisms underlying an association between psychosocial variables and the development of cancer. However, experimental work has now provided the groundwork for an investigation of such mechanisms. Advanced techniques for measuring immunological functions show that, rather than existing as an autonomous defense agency, the immune system is integrated with other physiologic processes. Moreover, it is subject to the influence of the central nervous system and endocrine responses that accompany psychological stress.

A new interdisciplinary research area, psychoneuroimmunology, examines the interrelationships among central nervous system, endocrine, behavioral, and immunologic processes (Ader, 1981). For example, laboratory stressors tend to decrease the responsiveness of the immune system in animals, and stress-responsive hormones, including corticosteroids, can alter, directly and indirectly, components of the immune response (Ader, 1981; Amkraut and Solomon, 1977). Animal and human studies demonstrate that laboratory and naturalistic stressors can reduce the number of lymphocytes (cells important in the immune process), lower the level of interferon (a substance which may prevent the spread of cancer), and cause damage in immunologically-related tissue (Ader, 1981).

Of particular relevance to cancer are other studies demonstrating that stress can inhibit the body's defenses against malignancy. For example, Riley (1975) reported markedly different latencies for mammary tumor development as a function of stress exposure in mice injected with a virus that induces tumors. Those animals housed under conditions of chronic environmental stress (e.g., crowding, noise) developed tumors with a median latency of 358 days, compared to a latency of 566 days in animals housed under protective conditions.

It should be emphasized that the relationship between stress and the immune system is by no means a simple one. Under certain conditions, enhanced immunity and increased resistance to cancers in response to stressors have been reported. Appropriate levels of hormones (e.g., corticosteroids) released under stressful conditions are essential for normal development and functioning of the immune system (Amkraut and Solomon, 1977). This suggests that the direction of stress-effects on the immune system—that is, whether immunocompetence is enhanced or depressed—may depend on the level of stress experienced, and resultant changes in hormonal levels.

The exploration of psychosocial influences on immune function constitutes an important area of biomedical research with implications for understanding cancer, as well as a variety of infectious diseases (see below). Further psychoneuroimmunological investigation is needed to isolate the variables that moderate the impact of stress on immunologic activity. There is also the possibility that certain groups of individuals (e.g., the elderly) may be particularly susceptible to psychosocially-induced alterations in immune response. This might occur because of documented changes in the immune system (Makidonan and Yunis, 1977), or because of psychosocial changes, such as decreased financial security and reduced mobility (Eisdorfer and Wilke, 1977) that accompany aging.

INFECTIOUS DISEASES

Exposure to contagious microorganisms does not invariably lead to disease. In fact, only a small percentage of infected persons actually become ill during disease epidemics. There is evidence that psychosocial factors can influence the acquisition, course, and recovery from infectious diseases via at least three mechanisms. These mechanisms parallel the processes linking behavior and physical illness outlined in the Introduction.

Health-Impairing Habits and Lifestyles

An individual's behavior can influence exposure to infection and the dose of pathogen. Poor nutrition and/or poor personal hygiene obviously increase illness susceptibility and delay recovery. In this regard, various behavioral and social factors (e.g., low socioeconomic status) are associated with increased incidence of infectious illness. Individuals in these categories are more likely to be exposed to harmful microorganisms, suffer from known health hazards at home and work, and have poor training in prudent, healthy ways of living. They may also have less access to quality medical care and are less likely to engage in preventive health practices (Institute of Medicine, 1978).

Direct Psychophysiological Effects on Immunity

As noted in the section on cancer, there is evidence that psychosocial factors affect the functioning of the immune system. This leads to increased susceptibility to immunologically-mediated diseases, and increased expression of the disease among those who are infected. Biobehavioral research has specified certain immunologic changes (e.g., reduced production or level of antibodies) that mediate these relationships.

With regard to infections, the immune system can be divided into three functional components: processes involved in transporting the invading microorganisms to the immune system; processes leading to the production of antibodies or immunologically active cells; and processes involving interaction between immunologically active substances and invading microorganisms. Neurohumoral factors can influence each of these immune mechanisms (Amkraut and Solomon, 1977). As with cancer, stress-related influences on susceptibility to infectious disease depend upon a complex of factors. These include the type of stress, type and number of invading microorganisms, mode of infection (e.g., air, contact, bloodstream), and the species of animal and its immunologic state at the time of inoculation (Ader, 1981; Amkraut and Solomon, 1977).

Psychoneuroimmunological research with animals has demonstrated that behavioral conditioning with noxious stimuli increases susceptibility to viral infections. In one study, neither exposure to a stressor nor inoculations with a virus was alone sufficient to induce disease in adult mice, but the combination of stress and inoculation with a virus elicited symptoms of viral disease (Friedman and Glasgow, 1966). In other studies, rats handled for brief periods of time early in life showed more vigorous antibody response to bacteria than did non-handled controls (Amkraut and Solomon, 1977). The impact of psychosocial stimulation on the immune response appears to be related to the dose of pathogen administered, as well as to the timing of exposure to the stressor (Amkraut and Solomon, 1977).

In humans, much of the evidence linking psychosocial stress to increased susceptibility to infectious diseases is derived from retrospective clinical studies, although there has been some promising prospective research. For example, Meyer and Haggerty (1962) studied the influence of family crises on factors that might modify susceptibility to streptococcal disease. In subjects observed over a one-year period, each family member was followed with periodic throat cultures and measures of immunologic function. Clinical ratings of chronic stress were positively related to streptococcal illness rate and levels of streptococcal antibodies in the blood. While close contact with infected family members and the season of the year influenced acquisition of a streptococcal organism, several respiratory illnesses were considerably more frequent after family episodes judged to be stressful.

A prospective study of infectious mononucleosis (Kasl et al., 1979) studied a class of military cadets—a population subjected to the rigors of military training and academic pressure. Among subjects susceptible to infectious mononucleosis (i.e., those without Epstein-Barr virus antibodies at matriculation), about one-fifth became infected each year with the virus, and one-quarter of this group went on to develop the clinical disease. Psychosocial factors that increased the risk of clinical disease among those infected included having a high level of motivation, doing poorly academically, and having "overachieving" fathers.

Behavioral Reactions to Illness

A third process linking behavior to the course of infectious illness involves treatment-seeking behavior and response to treatment. For example, a study of individuals in Maryland who had contracted Asian influenza during 1957-1958 revealed that clinical disease characteristics (e.g., serological response, height of fever, symptom severity) failed to distinguish those who recovered quickly from those who retained symptoms for longer periods of time. However, subjects with delayed recovery scored as more "depression prone" on psychological tests given in advance of the outbreak of illness. This finding was interpreted to indicate that depression-prone individuals exhibit greater concern over illness, which increased and prolonged their physical complaints and reports of illness. A prospective follow-up study measured actual frequency of infection via assays for rises in serum antibody titers. Among those who were infected, depression-prone subjects tended to develop the disease (thus suggesting a possible role of immunologic factors), but increased concern over the illness seems the most likely explanation for these findings (Cluff et al., 1966).

TREATMENT AND REHABILITATION OF PHYSICAL ILLNESS

THE PROSPECTIVE PATIENT AND THE MEDICAL ENCOUNTER

The provision of medical care depends, to a very considerable extent, on the social, psychological, and cultural processes that lead people to define themselves as requiring care (Mechanic, 1968). Many factors unrelated to the biological severity of illness combine to determine who receives care; persons requiring medical attention do not always seek out medical help and are not always seen by health care providers. These variables must be considered by practitioners and policy planners in the formulation and delivery of health care services.

Recognition of symptoms and resultant use of health care services are influenced by situational factors, such as life difficulties and psychological stress (Mechanic, 1968). Also important are learned patterns of behavior such as social roles and cultural norms; for example, females are more likely than males to visit health care professionals. Social class and cultural background influence patients' evaluations of symptoms and doctors' responses to patients' complaints. Age is another factor that determines reactions to symptoms and use of medical facilities; for example, the elderly take aches and pains for granted and place little faith in medical science, even though the frequency of use of medical facilities and concern with health increase with age (Riley and Foner, 1968).

PSYCHOLOGICAL AND PHYSIOLOGICAL ASPECTS OF PAIN AND ILLNESS

Much progress has been made in identifying socio-psychological correlates of pain and psychophysiological pain mechanisms, and in developing research-based techniques for pain control. Pain is more than a sensory experience; it is not a necessary consequence of injury or tissue damage. Definitions that imply that pain can be stopped simply by interrupting neural pathways are not adequate to account for clinically-related phenomena. For example, surgical interventions indicate a rather disappointing record of success (Weisenberg, 1977). People without known organic pathology suffer pain (Fordyce, 1976), and even when an organic basis for pain is established, psychological factors continue to affect the experience of pain.

A range of cultural, socio-psychological, and situational factors influence pain perception and tolerance (cf. Weisenberg, 1977). Different cultural groups have different views of appropriate pain reactions, including the circumstances under which it is permissible to cry or ask for help. Moreover, the influences of the social context and meaning of the pain experience produce differences between clinical and experimentally-induced pain. Pain in clinical situations involves anxiety associated with the disease process and fear of death (Weisenberg, 1977; Beecher, 1959), whereas experimentally-induced pain does not.

The Placebo Effect

A pervasive phenomenon in the pain literature is the placebo effect, that is, the reduction of pain or the removal of symptoms via medication or therapeutic treatment which has no identifiable active component (Shapiro, 1971). It has been estimated that placebo medication (e.g., pharmacologically inert substances) and other non-specific treatment factors reduce pain successfully in about 35% to 40% of patients (Beecher, 1959). Although the placebo response in medicine has been widely recognized, until recently it had been regarded as a nuisance variable. In pharmacological research, the routine inclusion of a control group receiving an inert medication has been considered an essential methodological control, particularly in evaluating psychoactive drugs. Mechanisms of the placebo response as a component of various therapeutic interventions have now come under study in their own right. Contrary to the popular belief that placebo effects are confined to psychological changes, there are data showing that placebos can produce a variety of changes on a physiological level, for example, significant blood pressure reductions among persons with HBP (Shapiro, forthcoming).

Psychosocial variables that enhance the effectiveness of placebos have been identified, thereby shedding light on the mechanisms of placebo action in pain relief. Person-centered approaches aimed at identifying patients responsive to placebos have not proven valuable. However, there is evidence that situational factors, which influence a patient's motivational and attentional processes, as well as a host of variables relating to doctor-patient interaction (e.g., expectations of relief, the patient's confidence in the physician and the procedures) can heighten placebo effects (Shapiro, 1971). Reduction of stress and anxiety also seems to be an important facet of placebo effectiveness (Beecher, 1959). It is likely that placebo-related factors, when fully understood, will provide a powerful tool in clinical practice.

Psychophysiological Models

The influential "gate control" theory of pain was proposed 15 years ago (Melzack and Wall, 1965) in order to integrate physiological and psychological factors in pain perception. This theory proposes that noxious stimuli activate selective central nervous system processes, which act to exert control over incoming messages. Influenced by this trigger mechanism, cells at each level of the spinal cord act as a gate-control system, increasing or decreasing their receptivity to incoming pain signals traveling along the nerves. This system makes it possible for higher mental processes, which underlie attention, emotion, and memories of prior experience, to alter transmission of pain signals (Weisenberg, 1977).

The posited physiological and anatomical bases for the gate-control theory have been subject to considerable criticism (e.g., Nathan, 1976; Liebeskind and Paul, 1977). However, a wide assortment of clinical and experimental findings have been interpreted as supporting the theory—or at least certain aspects of it (Liebeskind and Paul, 1977)—and the theory has led to the development of a technique for artificially stimulating the nervous system to relieve pain. Although subsequent work on endorphins calls into question some key details of the gate-control theory, the original theory and subsequent modifications have been influential in highlighting the importance of motivational and cognitive factors in pain experience.

The recent discovery of endogenous, opiate-binding receptors, and substances in the brain (endorphins) that bind with these receptors, has led to a new interest in central nervous system mechanisms of pain control. It has been demonstrated that a pain-suppression system exists in the brain which can be activated by psychophysiological procedures such as electrical stimulation (Liebeskind and Paul, 1977), and by environmental and psychological manipulations such as exposure to stress.

Recent research (Mayer et al., 1976; Levine et al., 1978) suggests that mechanisms of action of heretofore poorly understood phenomena of pain relief (e.g., acupuncture, placebo response) may involve this endogenous system.

The physiological involvement of endorphins is investigated by administering naloxone, a drug that specifically blocks the action of opiates. If an endogenous physiological process is blocked by naloxone, endorphins can be inferred to play a role in this process. Levine, Gordon and Fields (1978) investigated the possible role of endorphin activity in placebo pain relief, with patients who had just undergone painful dental surgery as the study sample. Naloxone was administered to half of the patients under randomized, double-bind conditions; the other half of the subjects received a placebo. Pain ratings were taken, and those patients previously given a placebo were further subdivided into two groups: those whose pain was reduced or unchanged (''placebo responders''), and those whose pain increased (''non-responders''). Patients were then randomly given a second drug, again either naloxone or a placebo. Results indicated that after the first drug administration, subjects given naloxone reported more pain than those given a placebo. Naloxone given as a second drug produced no additional increase in pain levels of placebo non-responders, but did increase pain levels of placebo responders. These data are consistent with a hypothesis that endorphin release mediates placebo pain relief for dental postoperative pain. This study is only an initial investigation of the possible role of endorphin activity in psychological pain phenomena. Future research on endorphins promises to have a profound impact not only on basic science and clinical understanding of pain, but also on a wide range of biobehavioral phenomena including addictive behaviors and mental illness.

COMPLIANCE WITH MEDICAL REGIMENS

In recent years, there has been a growing awareness that the failure of patients to adhere to prescribed medical regimens is probably the single greatest problem in bringing effective medical care to the individual patient. This problem also contributes in a major way to the economic and social costs of illness (Sackett and Haynes, 1976; Cohen, 1979). Although adherence varies, it is not uncommon to find compliance rates as low as 50% in many situations. It was estimated recently that only one-third of patients adhere correctly, that one-third are noncompliant because they adhere to a misunderstood regimen, and that one-third are knowingly noncompliant (Cohen, 1979).

The medication compliance problem may be most pronounced for chronic illnesses, such as high blood pressure, where effective therapy requires regular, long-term taking of medications that may produce unpleasant side-effects (Sackett and Haynes, 1976). However, noncompliance is a problem in areas of the treatment process other than adherence to regimen. Substantial numbers of patients who do not have painful symptoms fail to come for scheduled appointments, and the problem of inducing and maintaining change of unhealthful habits (such as diet and smoking) is particularly formidable.

A good deal of attention has been given to isolating factors that influence or predict compliance (Becker, 1979; Sackett and Haynes, 1976). Surprisingly, common demographic variables such as age, sex, and marital and socio-economic status have little independent influence. The crux of the problem is often poor doctor-patient communication, rather than the patient's behavior alone. Two sets of variables deriving from the physician-patient encounter—satisfaction with care and comprehension of the treatment regimen—appear to effect compliance.

Aspects of the doctor-patient relationship determine satisfaction, and satisfaction determines the degree to which medical advice is accepted. For example, a study in a pediatric setting (Korsch and Negrete, 1972) found that a major source of mothers' dissatisfaction was the failure of physicians to answer questions and provide clear explanations of illness. More than 80% of those who thought the physician had been understanding were satisfied, as compared to only one-third of those who did not feel that the doctor tried to understand their problems. If mothers were dissatisfied with the communicator (i.e., the doctor) or the content of the consultation, they were less likely to comply with the physician's advice.

A second aspect of the compliance problem is the patient's ability to comprehend and recall details of the treatment regimen. Much of the failure to follow doctors' orders is due to genuine problems in understanding and remembering what is told (Ley and Spelman, 1967). Often, the material presented by the doctor is too difficult to understand, the treatment regimen itself is overly complicated, or patients hold misconceptions about illness or human physiology which lead to confusion.

The causes and consequences of comprehension problems are illustrated by a study in which physician-patient interactions were observed for a lower-class clinic sample (Svarstad, 1976). Reviews of medical records and pharmacy files, follow-up interviews, and validation of patients' reported behavior via pill counts were made. The data revealed that patients did not always leave the clinic with an accurate perception of what physicians expected them to do. Frequently, physicians were not explicit in discussing their expectations with the patients. When physicians did make efforts to motivate compliance by being friendly, appealing to reason, or checking on previous compliance, many more patients conformed to the prescribed regimen.

Maintaining Adherence to Regimens

The crucial challenge for medical compliance, as with the modification of other health-impairing behaviors, is to maintain people on prescribed regimens for sustained periods. This problem is illustrated by the remarkably similar relapse rates among subjects treated in programs aimed at weight reduction, smoking cessation, and reduction of alcohol consumption (Hunt et al., 1979). Two-thirds of such patients abandon the regimen and backslide by the end of three months, and only about one-quarter of the individuals maintain changed behavior at the end of a one-year period.

One technique used to help maintain long-term adherence to treatment regimens involves a focus on the immediate rewards and consequences of compliance or noncompliance. A range of "behavior modification" procedures, based on principles of operant learning, have proven the most effective (Pomerleau and Brady, 1979). Interventions to increase adherence must also recognize those characteristics of the social interactions of physicians and patients that foster noncompliance.

Most of the research on medical compliance has been designed to solve practitioners' everyday clinical problems, rather than to develop a comprehensive theory that may apply across a broad range of medical situations, illnesses and behaviors. However, one conceptual approach that has received some support in explaining medically-related behaviors (including compliance) is the Health Belief Model. This model centers on the patient's views about the appropriate paths of action in the presence of health disturbances, perreptions of barriers to action, and subjective interpretations of symptoms (Becker, 1979). Still more effective approaches are needed that encompass the physician-patient communication process and suggest ways of making the rewards of long-term medical compliance more salient to patients.

THE SMOKING PROBLEM: AN EXEMPLAR OF HEALTH-IMPAIRING BEHAVIOR

The cigarette smoking habit has been described as the single most preventable cause of death in the United States (U.S.D.H.E.W., 1979a). Yet, despite the fact that knowledge of the health risks of smoking has reduced the percentage of adults who regularly use cigarettes, there are still over 50 million smokers in the U.S. today. Moreover, in recent years there has been an alarming increase in the proportion of teenagers (particularly females) who are taking up the smoking habit. With regard to the modification of smoking behavior, the problem is not that the public is unaware of the negative health consequences, but that the great majority of smokers are unable to quit or stay off cigarettes for *prolonged* periods (Leventhal and Cleary, 1980; Bernstein and Glasgow, 1979).

Cigarette smoking is a behavior whose initiation, maintenance, and cessation are determined by a mixture of social, psychological, and physiological factors. Many of the problems faced in attempts to prevent and modify the smoking habit are also associated with the correction of other health-impairing habits, lifestyles, and dependencies (e.g., poor diet, alcoholism, lack of exercise). We will give considerable attention to the smoking problem to illustrate behavioral science approaches to these health-impairing behaviors.

Initiation and Prevention of Smoking

Cigarette smoking can be viewed as the product of a multi-stage process that begins with initial experimentation with cigarettes and leads to the acquisition of a habit and/or addictive process (Pomerleau, 1980). Data suggest that even limited adolescent experimentation with smoking may lead to habitual smoking (Leventhal and Cleary, 1980). Psychosocial factors related to initiation of smoking include social pressure from peers; imitation of adult behavior; adolescent rebellion and anti-social tendencies, and personality factors such as extraversion—a biologically-based dimension related to arousal or stimulation-seeking. A social learning explanation of smoking initiation (Bandura, 1977) assumes that the habit is acquired through imitation and social reinforcement, typically under the influence of peer pressure, media stereotypes, etc.

The inhalation of smoke is initially somewhat aversive, but after sufficient practice, pharmacological habituation (or tolerance) occurs, and the behavior produces enough satisfaction or reward in its own right to maintain the habit (Pomerleau, 1980). The delayed negative health consequences, but immediate social and biological rewards of smoking, may account for many of the difficulties in modifying the habit once it becomes established (Jarvik, 1979).

Early efforts to prevent smoking assumed that this could be accomplished by teaching young people the health consequences of this habit. But the results were largely disappointing (cf. McAlister et al., 1979). However, several projects have obtained encouraging results by employing socio-psychological techniques of communication and attitude change to deter smoking in adolescents. A pioneering effort in the area, The Houston Project, is a three-year longitudinal study (Evans et al., forthcoming). This project created persuasive films and posters to teach young teens (grades 7-9) about peer and media pressures to smoke, and about effective techniques for resisting pressures. Other films demonstrated the immediate physiological consequences of smoking (e.g., carbon monoxide in the breath). Hundreds of students in matched experimental and control groups were compared for cigarette smoking rates at the start of the project and during the three-year follow-up. The results indicated a significant impact of the films and posters: experimental subjects smoked less frequently, and expressed less intention to smoke compared to a control group receiving no intervention (Evans et al., forthcoming).

Maintenance of the Smoking Habit

Once smoking is established, both psychological and biological factors contribute to its persistence and resistance to change. Learning mechanisms, possibly in conjunction with physiological satisfactions derived from smoking, play a considerable role in maintaining the habit (Hunt and Matarazzo, 1970). The use of cigarettes becomes part of a chain of behaviors: taking out the package, lighting the cigarette, getting tobacco smoke, etc. As a result, the aforementioned stimuli *associated* with smoking come to elicit pleasurable responses by themselves. In addition, the avoidance of unpleasant withdrawal effects (e.g., craving) becomes rewarding, thus helping to maintain the habit (Russell, 1979). These observations receive more systematic support from animal research which demonstrates that drug responses (e.g., morphine tolerance) can become conditioned reactions, and that withdrawal symptoms can be conditioned to external cues (Siegel, 1979).

Learning or conditioning mechanisms alone are not sufficient to explain the maintenance of smoking, since many smokers will increase intake to regulate or achieve a particular level of nicotine in their system (Schachter et al., 1977). Biological factors figure prominently in the maintenance of the habit, and nicotine is the chemical in tobacco that is most likely responsible for these effects (Jarvik, 1979). However, the question of whether cigarette smoking can be considered an addiction comparable to heroin or alcohol addiction remains a subject of scientific debate (Russell, 1979).

Tobacco has the capacity to elicit many of the defining characteristics of an addictive process, and there has been recent biobehavioral research on the complex interplay of psychological and pharmacological processes leading to smoking behavior. For example, a *nicotine-regulation* hypothesis asserts that heavy smokers adjust their smoking rate to keep nicotine at a roughly constant level, and that the rate of smoking depends on the rate of nicotine excretion and breakdown by the body. The rate of nicotine excretion depends, in part, on the acid-base balance (pH) of the urine, which, in turn, can be altered by psychological stress or anxiety. Thus, it is argued that the links between psychological processes, the craving for cigarettes, and increased smoking are mediated by a physiological addiction mechanism involving the pH of urine (Schachter et al., 1977).

A series of programmatic studies (Schachter et al., 1977) provide support for this hypothesis. First, a sample of long time heavy smokers consistently smoked more low than high nicotine cigarettes, thus showing that smokers "regulate" nicotine intake. Next, it was shown that when urinary pH was manipulated by the administration of acidifying or alkalizing agents, smokers smoked more when urine was acidified. A third set of studies examined the urinary pH-excretion mechanism as a mediator of psychological determinants of smoking rate. Urinary pH was found to covary with naturalistic situations (e.g., party-going; examinations) associated with heavier smoking. Schachter's point is that the influence of psychological variables (such as stress) on smoking rate operate only because of their effects on the urinary pH mechanism. Support for this was provided by a laboratory experiment which independently manipulated stress and urinary pH. Results indicated that smoking covaried with pH, rather than stress.

However, there remain several exceptions to the nicotine-regulation model. There are different types of smokers, some of whom do not appear to smoke for nicotine content (Schachter et al., 1977). In addition, the Schachter model suggests that lowered nicotine content of cigarettes will increase the number of cigarettes smoked, and data in this regard are, at best, contradictory (Garfinkel, 1979). Nevertheless, the nicotine-regulation hypothesis has identified a biobehavioral mechanism for cigarette addiction.

Withdrawal

Because of the addictive component of smoking, it is crucial to understand the withdrawal process in order to develop effective intervention strategies to modify the habit. However, most research efforts have concentrated on the effects of cigarette smoking, rather than on the effects of cessation, i.e., irritability, sleep disturbances, inability to concentrate, and weight gain (Schachter, 1978).

Recent research by Grunberg (1980) suggests that weight gain accompanying withdrawal from nicotine may result from increased preferences for sweet-tasting foods. Smokers allowed to smoke ate fewer sweets than did nonsmokers or deprived smokers. The three groups did not differ in consumption of nonsweet foods. A parallel study with animals showed that nicotine administration retarded normal body weight increase in young rats. Cessation of nicotine was accompanied by marked increases in body weight and concomitant increases in consumption of sweet foods. Moreover, these effects could not be explained by changes in total food consumption or activity level.

Ability to put up with the withdrawal syndrome is crucial to the maintenance of smoking cessation. Therefore, further investigation of mechanisms responsible for symptoms accompanying withdrawal may suggest techniques for controlling the high recidivism rate among those who quit smoking.

Modification of Smoking Behavior

Most of the effort in the smoking area has been directed toward the development of smoking-cessation strategies. Many of the earlier intervention studies suffered from problems of experimental design (e.g., lack of adequate control groups), and difficulties in measuring smoking-cessation objectively. There was also a high early dropout rate, sometimes reaching 50% of subjects included in the initial sample, which may spuriously inflate the initial success rate (cf. Leventhal and Cleary, 1980; Pomerleau, 1980). More recent work has enabled some systematic evaluation of the long-term efficacy of smoking-cessation programs and techniques.

Therapy Approaches These approaches include individual and medical counseling, hypnosis, group therapy, and behavioral therapies derived from the learning theories of experimental psychology.

Research indicates that most therapy techniques are effective in promoting short-term cessation of smoking, but usually fail to keep more than 50% of ex-smokers off cigarettes for long periods of time (Bernstein and Glasgow, 1979). Systematic study of the important area of maintenance of nonsmoking is just beginning, and strategies such as long-term group support and behavioral techniques for coping with anticipated withdrawal symptoms are promising. A number of the public health studies described below incorporate components of behavioral therapy approaches. Successful long-term smoking-cessation results obtained by these studies are due in part to therapy techniques.

Public Health Approaches It appears that significant reductions in adult smoking, especially among middle aged males and certain professional groups, can be attributed to information and educational campaigns initiated after the first Surgeon General's Report on Smoking in 1964 (Pomerleau, 1980). In recent years, several large-scale media-based projects have been undertaken in the United States and Europe to change attitudes and behavior related to smoking.

The Stanford Heart Disease Prevention Project was designed to reduce a broad range of risk factors including smoking (Farquhar et al., 1977; Meyer et al., 1980). Three communities were studied: one served as a control; a second was exposed to a mass media campaign on heart disease risk factors, including smoking; and a third received the mass media campaign and face-to-face behavioral therapy for selected high-risk persons. The media campaign alone produced some reductions in smoking at long-term follow-up. More substantial reduction occurred when the media campaign was supplemented by face-to-face therapeutic instruction. These findings are encouraging, but must be evaluated cautiously because of several methodological problems inherent in risk factor studies of this sort—namely, the high dropout rate and/or other difficulties encountered when subjects do not adhere to the randomly assigned interventions involving lifestyle changes (Kasl, 1980).

Another ambitious study, in Finland (Puska et al., 1978), introduced a nationwide multiple-component program, including televised counseling sessions. These were designed to prevent relapse by educating participants in behavioral techniques for coping with anticipated relapse problems (e.g., stress, weight gain). About 40,000 adult smokers participated in the study; as a result of the program a small but significant percentage achieved sustained abstinence from smoking at six-month and one-year follow-ups (McAlister et al., 1980).

The Stanford and Finnish programs represent impressive, and perhaps, cost-effective efforts to induce large numbers of people to abandon the cigarette habit on a long-term basis. These and related studies, however, have not produced unequivocally successful outcomes (Leventhal and Cleary, 1980; Kasl, 1980).

Nonetheless, they do suggest that meaningful changes in smoking behavior via public health approaches are possible, but only when the risks of smoking are made immediate and salient, and both skills and support to change smoking behavior are provided (Pomerleau, 1980). The more important question of whether risk factor (e.g., smoking) reduction will lower morbidity and mortality, particularly from cardiovascular diseases, is being studied directly by large-scale intervention trials now underway. These projects will be discussed in the last section of this chapter.

OTHER BEHAVIORAL THERAPIES IN HEALTH CARE

The increasing importance of behavioral and social sciences in medicine is due, in part, to the development of effective procedures for changing illness-related behaviors. Several of these behavior modification techniques, which were designed and evaluated for the prevention, management, and treatment of physical disease (Pomerleau and Brady, 1979), have already been alluded to in the discussions of medical compliance and cigarette smoking. Other health-care applications are in the areas of pain control, childhood disorders, adult psychosomatic disorders, rehabilitation of the disabled and physically ill, and geriatric problems (Melamed and Siegel, 1980). Four representative behavioral techniques are described below.

Operant Control of Chronic Pain

Pain reactions can persist long after the original physiological sensation and tissue damage have been remediated. Fordyce and others (1976) have developed a successful technique for treatment of chronic pain through the application of *operant conditioning* procedures. Many pain-related behaviors become established and maintained by the particular rewards they provide for the patient, for example, attention from family, staying home from work, as well as pain relief. Environmental rewards (e.g., attention from family and/or hospital staff) are therefore manipulated so that the value of undesirable pain behaviors is reduced or removed.

Cognitive-Behavioral Interventions

These techniques are designed to reduce pain and the aversiveness of medical procedures (e.g., surgery) by diminishing perceived threat and the psychological stress associated with medical procedures (Turk and Genest, 1979). Since the physiological and/or behavioral components of the stress response (e.g., excessive sympathetic nervous system activity; lowered motivation or ability to comply with medical regimens) may also interfere with the recovery process (cf. Krantz, 1980), there is some indication that stress-reduction procedures can speed recovery. Some of these procedures (e.g., psychological preparation of children for hospitalization) are being applied routinely (Melamed and Siegel, 1980).

Biofeedback

Until recently, it was believed that the responses of the autonomic nervous system were involuntary and that an individual could exert little or no control over these processes. However, visceral responses such as heart rate, blood pressure, and skin temperature can be controlled voluntarily when feedback is provided to the individual for altering these responses (cf. Miller, 1969). Biofeedback training teaches the individual to monitor physiological responses through the use of electronic instruments. When a subject alters a physiological state (e.g., heart rate, muscle tension, electrical activity of the brain), he or she is provided with auditory, visual, or other feedback indicating that the correct response has been made. The feedback is effective in teaching subjects to control the physiological response because it tells them that their motivated attempts to alter the response are effective. Thus, the feedback serves as a reinforcer (reward), which leads to learned control of the physiological response (Miller, 1969).

Recent research has explored the clinical utility of biofeedback techniques for such disorders as high blood pressure, migraine headache, seizure disorders, sexual dysfunctions, and muscular paralysis (Gatchel and Price, 1979; Ray et al., 1979). A particularly effective clinical application has been in the treatment of neuromuscular disorders. For example, through the use of feedback for activity of muscle units (cells), paralyzed or damaged muscles may once again come under voluntary control. Dysfunctions such as cerebral palsy, muscular spasms, and various paralyses have been successfully treated by biofeedback. Often, these dysfunctions were previously unresponsive to traditional physiotherapies and medical or surgical treatment (Ray et al., 1979).

The initial enthusiasm for biofeedback probably exaggerated its therapeutic effectiveness. Further research has revealed limitations in the use of this technique. For example, it must still be established that training in laboratory or clinic generalizes to real-life settings, and there is need for more research evaluating the relative effectiveness of biofeedback versus other therapeutic techniques.

Relaxation Training

Relaxation therapies are procedures designed to elicit physical and emotional calmness in order to decrease autonomic nervous system arousal, muscular tension, and other physiological correlates of psychic trauma. The most common technique is deep muscle relaxation (Jacobson, 1938), which involves supervised practice in the systematic relaxation of major skeletal muscle groups. Relaxation therapy is effective in the treatment of a variety of psychophysiologic disorders, including high blood pressure, migraine headache, and chronic pain syndromes (Melamed and Siegel, 1980).

OUTLOOK FOR THE NEXT FIVE YEARS

An important priority for research in the next five years is the integration of behavioral and biomedical knowledge in a way that elucidates the mechanisms underlying the interplay among behavior, physiological processes, and somatic dysfunctions. Accordingly, the key issues for biobehavioral inquiry include further study of features of the behavioral context and of the individual (e.g., coping styles, biologic predispositions, availability of social supports), which may determine the outcome of exposure to stressful events. Also suggested are further studies of psychophysiological mechanisms that mediate behavior-disease linkages, particularly those involving neuroendocrine and immune responses. Other priorities are the development and evaluation of techniques to produce sustained changes in behavioral risk factors. This includes research on mechanisms of smoking addiction and withdrawal, and prevention of health-impairing habits. The important area of medical compliance requires more theoretically-based research taking into account doctor-patient communication and the cognitive/motivational factors that sustain adherence to treatment regimens.

BIOBEHAVIORAL PARADIGM FOR RESEARCH INTO THE ETIOLOGY AND PATHOGENESIS OF PHYSICAL DISEASE

Psychosocial Stress

As noted earlier, stress has been implicated as a central factor in the etiology of cardiovascular illness and also may play a role in the development of peptic ulcer, cancers, and infectious diseases. The association of psychological stress with somatic disorders underscores the importance of research aimed at (1) understanding when and under what conditions stress becomes translated into physical diseases; (2) specifying the physiological and neuroendocrine pathways through which stress-reactions potentiate illness; and (3) identifying factors which predispose individuals to one stress-related disorder rather than another (cf. Graham, 1972).

Conditions for the Stress-Disease Relationship Stress is probably an inevitable aspect of modern living; the struggles, conflicts, and frustrations that threaten individual well-being seem an inherent quality of the human condition. Yet, stress-related diseases are far from universal. It would appear that personal attributes and situational variables exert an important influence in modifying the outcomes of psychological stress (Cohen et al., 1981). Among the more promising of these modifiers are sociocultural resources, including direct help or emotional support from other people and the health-care system. Also important are particular psychological characteristics of stressors, such as whether they are predictable or within the individual's ability to control. In addition, biological predispositions and acquired factors such as styles of coping may mediate the impact of stressors, thereby influencing the likelihood of a disease outcome (Cohen et al., 1981). Thus, univariate studies linking indices of stress with disease endpoints must be supplanted by multivariate research in which the stress-moderating effects of biological, psychological, and sociocultural variables are taken into account.

For research to be cost effective, psychosocial variables must, where appropriate, be examined in conjunction with ongoing biomedical studies. For example, the National Institutes of Health are currently funding a number of Specialized Centers of Research (SCOR), which are concerned with various aspects of cardiovascular disorders in children and adults (U.S.D.H.E.W., 1978). Given the importance of behavioral variables in these disorders, valuable scientific data at a relatively low cost would be provided by incorporating behavioral components in these studies. For example, a psychosocial component was included in the Framingham Heart Study cohort examined in the late 1960's. Results of this study, reviewed above, provided useful information supporting the importance of behavioral and social variables in the etiology of coronary heart disease (cf. Haynes et al., 1980).

Psychophysiologic Mechanisms Research on the psychophysiological pathways linking stress to disease will require continued technological improvements to facilitate the measurement and identification of neuroendocrine, central-neural, and related processes. Animal models will play an important role in such research (cf. Ader, 1976; Campbell and Henry, forthcoming). The study of pathophysiological mechanisms often relies upon procedures that cannot be used with human subjects. These procedures include the use of surgical interventions and electrical stimulation as means of identifying sites that regulate bodily reactions to stressful events. Drugs that selectively stimulate (or block) the activity of suspected mediating structures, such as the receptor sites of the sympathetic nervous system, provide a direct means of assessing the impact of stress-related physiologic processes upon target organs whose dysfunction is suspected to be of psychogenic origin (e.g., Obrist, 1981).

Human research models, will however, remain indispensable, especially in the study of cognitive and perceptual variables that initiate and regulate physiological reactions to stressful stimuli. Experimental research is essential and justifiable for making progress in this area where no demonstrable damage to subjects can be discerned. Where ethical and practical concerns limit the applicability of laboratory methodologies in studying a problem area, it is frequently possible to conduct studies of populations who are exposed to the variable of interest under natural conditions.

Recent developments in psychophysiological measurement make it possible to measure the influence of behavioral variables on physiological processes in naturalistic settings, such as home or workplace. These techniques have opened new frontiers in biohavioral research. For example, a recent study successfully utilized a portable electronic device to provide blood pressure biofeedback aimed at preventing fainting, thereby aiding in the rehabilitation of paralyzed patients (Miller, 1979). Another study (Dimsdale and Moss, 1980) utilized a portable blood withdrawal pump to monitor plasma hormone levels during periods of emotional stress and exercise.

A focus on mechanisms linking behavior and health is required in order to translate historical and epidemiological descriptors, such as age, personality, genetics, or nutritional history, into psychophysiological processes that can be modified or altered (Schwartz et al., 1979). To influence medical practice, behavioral and social science research must identify modifiable variables involved not only in the etiology of disease, but also in the progression of illness after symptoms have appeared (Stachnik, 1980).

The Specificity Problem The study of factors that selectively predispose individuals to particular disorders must incorporate examination of both traditional risk factors (including genetic predispositions) and acquired behaviors (such as coping styles), as well as features of the situation (e.g., exposure to particular types of stressors).

Both animal and human research models need to be used in exploring issues of selective susceptibility to disease. The controlled breeding of infra-human species can facilitate the study of genetic and behavioral interplay. For example, several strains of rats susceptible to stress and salt-induced HBP have been produced through selective breeding (Campbell and Henry, forthcoming). Similarly, genetic strain appears to influence susceptibility to gastric lesions caused by experimental immobilization (Weiner, 1977).

Human research also should contribute to the study of biobehavioral factors that make for vulnerability to specific physical diseases. Recall that subjects with a family history of hypertension exhibit enhanced blood pressure response while working at a demanding task (Obrist, 1981). A similar research strategy could be used to study physiological changes in subjects with a family history of other disorders. For example, stress-induced changes in serum glucose levels might be studied in individuals with diabetic parents. This type of research should be supplemented by studies of twins and prospective research employing longitudinal designs.

Type A Behavior Pattern

One illustration of a developing area of mechanism-oriented biobehavioral research is the study of the Type A "coronary-prone" behavior pattern. Having demonstrated its association with coronary disease, research now is addressing issues similar to those discussed in the section on psychological stress: (1) isolation of aspects of the behavior pattern that confer enhanced risk; (2) identification of the psychological mechanisms that produce and sustain coronary-prone behavior; (3) specification of the physiological processes that account for the enhanced risk of individuals displaying coronary-prone behavior (Glass, 1981). Subsequent studies (probably with animal models) might be undertaken to elucidate cause-and-effect. That is, do animals bred or trained to exhibit Type A behavioral characteristics show elevated physiological reactivity, or are the behavioral responses caused by physiological reactivity? Indeed, both behavioral and physiological reactions may be consequences of a third variable located elsewhere in the nervous system.

Psychoneuroimmunology

The emerging field of psychoneuroimmunology also holds great promise (cf. Ader, 1981). Exploration of basic mechanisms of immune changes produced by psychological stimuli will continue to be an active area of research. In addition to controlled laboratory experimentation with animals, there is a need to determine if reliable, replicable, and clinically meaningful alterations in immune function in humans are associated with psychosocial variables (e.g., certain life stressors, coping styles, or both of these acting together). Other research priorities for this field include the study of correlated changes in neuroendocrine and immune functions across the life span (development immunology); studies of possible learning and conditioning effects on the immune system; and prospective studies relating behavior to processes of immunologically-mediated diseases (Ader, 1981).

Methodological Issues

The complexities involved in integrating behavioral and biomedical knowledge will require multifaceted research strategies. What is needed is a continual interplay between laboratory and field methodologies. This interplay may take several forms. For example, an effect can be established as reliable with controlled laboratory experimentation, where causal links can be inferred. The generality of the relationship can then be established in subsequent research in natural settings (e.g., home, workplace) (cf. Cohen et al., 1980). Similarly, by first conducting field studies, it is possible to isolate important dimensions of a particular research area. At that point, laboratory studies may be useful to rule out alternative explanations often inherent in naturalistic research. A vivid example of this methodological interplay is provided by data on biobehavioral factors in the etiology of high blood pressure. Naturalistic and clinical evidence suggested that psychosocial stress plays a role in this disorder. Accordingly, laboratory studies were undertaken to isolate the psychophysiological mechanisms involved in behavioral responses to environmental stressors. Further naturalistic work (e.g., Rose et al., 1978) extended the laboratory findings by demonstrating that exaggerated blood pressure responses to high work loads were predictive of sustained hypertension (Herd, 1978).

RISK FACTOR MODIFICATION AND PREVENTION: RESEARCH ISSUES AND FUTURE DIRECTIONS

Associations between major chronic diseases and seemingly modifiable behavioral factors have spurred interest in relating behavioral knowledge to health promotion and the prevention of disease (Breslow, 1978; Matarazzo, 1980). The present body of research in this area constitutes only a promising beginning, and it is wise to be cautious about making unequivocal claims of success based on existing evidence. However, this emerging research area does raise important challenges and questions.

Maintaining Abstinence

While there are encouraging indications that established patterns of behavior can be changed in the short-term, a major difficulty has been maintaining these changes in substantial numbers of individuals over sustained periods of time (Bernstein and Glasgow, 1979; Hunt et al., 1979). There is also a high early drop-out rate in various treatment programs (cf. Leventhal and Cleary, 1980). Work in these areas by behavioral scientists will intensify in the next five years and must focus on understanding factors that initiate and maintain health-impairing habits, and not just on techniques to modify and prevent them.

For some habits, such as smoking or drug abuse, biological factors are intimately involved at all stages of the problem. Considerable attention must be given to the psychobiological and psychosocial aspects of the withdrawal and behavior change processes themselves (Leventhal and Cleary, 1980). Smoking, dietary, and exercise habits, and health-endangering practices such as failure to use seat belts, alcohol abuse, and poor hygiene also must be studied as sociocultural phenomena. Decisions to engage in or modify health-impairing habits, and the incorporation of changed behaviors as part of an overall lifestyle, all occur in a social context (Syme, 1978).

Antecedents of Habits and Risk Factors

Habits and lifestyles develop in the context of family and society; hence, more research is needed on the socialization of health-related habits. Such longitudinal and cross-cultural research is expensive, but may be conducted in a cost-effective manner in conjunction with ongoing longitudinal studies of the development of disease risk factors in children. For example, a number of projects are being carried out among populations of school-age children (e.g., the Bogalusa Heart Study, Voors et al., 1976) to track the distribution and time course of heart disease risk factors such as blood pressure and serum lipids. Behavioral and social variables, including family health values and habits could be incorporated into such projects. A behavioral interface with biomedical research would also provide an excellent opportunity to examine the processes involved in the socialization of health lifestyles.

Prevention

Primary prevention (i.e., before disease develops) of health impairing habits, and the promotion of healthy lifestyles for people of all ages are cost-effective approaches to health. For in the long term, the potential costs in lives and dollars of treating disease are likely to outweigh the costs of preventing unhealthful habits. Social learning approaches to smoking prevention have yielded promising results in the Houston school-based intervention (Evans et al., forthcoming). Further work with children and adolescents might expose other habits to social learning interventions. More systematic research with adults also is needed. The workplace has proven to be a promising setting for such efforts. People spend considerable time at work, and many employers sponsor such programs because of the benefits that accrue from healthier employees.

The terms "secondary prevention" and "tertiary prevention" refer, respectively, to interventions taken to arrest the progress of illness already in early asymptomatic stages, and interventions to stop the progression of a clinically manifest disease (Institute of Medicine, 1978). Secondary and tertiary prevention activities involving behavioral factors may be more feasible than primary prevention, given the present state of knowledge. Advantages of such interventions are that target groups can be easily recognized and are motivated to change their behavior (cf. Institute of Medicine, 1978).

Modification of Type A Behavior

Various therapeutic approaches have been proposed for modifying the Type A pattern (Roskies, 1980). Behavioral techniques, such as relaxation training have been proposed as a way of reducing stress-related bodily responses elicited in Type A individuals. Other strategies for modifying Pattern A have been designed to induce behavioral change. One such technique involves having the subject imagine situations that normally elicit Type A behaviors, and covertly rehearse alternative, Type B responses. Group therapy procedures also have been used in some studies with post-MI patients. Efforts to evaluate the effectiveness of these procedures have yielded encouraging results, but care must be exercised in drawing definitive conclusions. Preliminary evidence suggests a reduction in cardiovascular complications and in Type A behaviors (Friedman, 1979; Roskies, 1980).

Systematic research aimed at assessing modification procedures for Type A behavior is certainly one of the priorities in this area. However, large-scale trials may be premature at this time. A more pressing priority is to delineate the particular features of the behavior pattern that are risk-enhancing as well as the psychological factors that give rise to and sustain Type A behavior.

Determining the Impact of Behavior Change on Morbidity and Mortality

The presumably causal associations between behavioral factors and chronic diseases imply that effective modification of habits and behavior patterns will reduce the incidence of and mortality from these disorders. This assumption is complex and requires further evidence before it can be accepted. In the case of cigarette smoking, epidemiological data reveal that former cigarette smokers experience declining overall mortality rates as the years of discontinuance of the habit increase (U.S.D.H.E.W., 1964). Data on morbidity are more complex, and indicate that the benefits of being an ex-smoker are not as high as the benefits of never having smoked. Similarly, the data on the effects of reduced blood lipids on CHD are not conclusive (Kasl, 1980). Indeed, they suggest that factors such as the age at which reductions occur and the underlying mechanism for lipid elevations make a difference in the benefits that accrue.

Convincing evidence that risk factor modification reduces disease incidence and mortality can be obtained only from experimental or clinical trials. Several primary prevention trials (selecting subjects free of disease at entry into the study) are underway to determine if altering diet, smoking, and controlling high blood pressure will lower the incidence of coronary heart disease. One such project, initiated in 1973, is called MRFIT, that is, the Multiple Risk Factor Intervention Trial (Collaborating

Investigators, 1976). It involves nearly 13,000 high-CHD-risk individuals, half of whom were randomly assigned to a special intervention program consisting of health education, behavior modification, group support approaches, and a maintenance program to prevent recidivism. The other half of the subjects received annual medical exams only. Another project, the Stanford Five Cities Program (Farquhar, 1978), is an extension of the first Stanford media-based intervention, with follow-ups being taken to determine heart disease morbidity and mortality.

Data regarding risk factor reduction in these two studies have not yet been published. It is not known how large a reduction in risk factors is necessary to observe a decrease in heart attacks in these populations. Results are expected to be available for the MRFIT in the next two years.

Clinical trials of lifestyle interventions face the problems of behavioral measurement and of maintaining continued adherence to regimens (Kasl, 1980; Syme, 1978). Despite these disadvantages, such studies are major field trials of therapeutic and preventive measures which are relevant to the formation of public policy regarding behavior and health.

CONCLUDING COMMENTS

The final section of this chapter has highlighted the more promising research areas in behavior and health. Foremost among these are the study of psychosocial stress and the mechanisms linking stress and illness; psychoneuroimmunology; the challenge of maintaining abstinence from health-impairing behaviors; and techniques for enhancing medical compliance.

The biobehavioral approach to somatic health and illness is, by definition, an interdisciplinary venture. It requires the contributions of researchers representing a variety of skills and perspeitives. Provision needs to be made for training investigators in the integrative skills necessary for continued progress in the scientific study of behavior and health.

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3 Advances in Methods for Large-Scale Surveys and Experiments[1]

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SUMMARY

One of the most visible contributions of the social sciences to modern society has been the methodology of survey research, in which a sample of the population is studied. In gathering information, political pollsters, market researchers, and government agencies all rely on techniques that have been devised, applied, and then refined by social scientists and statisticians. Virtually every important policy decision, whether it is made by a corporation or by a federal agency, requires systematically collected information. This paper describes recent advances in the design, measurement, and analysis procedures that are employed in large-scale surveys and social policy experiments.

Surveys are conducted to obtain information that is not only accurate for the particular groups questioned, but also accurate for some larger population from which those groups are drawn. For many surveys, simple methods of probability sampling allow the researcher to estimate the deviation of sample findings from those that might exist for the entire population of interest. However, when a study is intended to assess the effects of an experimental treatment, such as an income maintenance program, or to gather information on special subgroups within the population, then simple methods of probability sampling are inadequate. Sampling techniques have been developed to minimize the costs of collecting information and at the same time provide accurate data for the researcher or policy maker.

Even when an appropriate sample is selected, numerous sources of error arise in interviewing. Is the respondent's memory accurate for past events? What if a question is unanswered? What if the respondent lies or is predisposed to give socially desirable answers? What if an interviewer records a response inaccurately? Various strategies have been developed either to anticipate and guard against these difficulties prior to the survey or to take them into account once the data are collected. Factors such as the impact of the content and the ordering of questions, characteristics of the interviewer, and even the type of situation in which the information is collected are considered. While interviews in person or by telephone or mailed questionnaires are the most common survey procedures, there is also a new approach to interviewing called Computer Assisted Telephone Interviewing (CATI), which promises to provide greatly increased flexibility in tailoring interviews to each respondent. Although many techniques to minimize errors in the collection of survey data involve the collection process itself, statistical techniques have been developed to compensate for known gaps and inaccuracies in already collected data sets.

Many survey research techniques are used in longitudinal studies and social policy experiments, often federally funded. Through the use of proper statistical methods, a broader and more reliable base of knowledge of the education, employment, income and health of the population has been developed.

Survey research technology is employed throughout American society. Furthermore, it is a technology that is undergoing constant innovation and revision, with techniques developed in one setting applied and modified for another. Yet these methods constantly receive the meticulous attention of academic statisticians and researchers. The sociologist, political scientist, or economist investigating basic questions about human behavior relies on the same survey methods employed by business and government. The research described here suggests that far from being a stable set of known tools, survey methodology is an active research field that provides continual benefits in the form of usable knowledge.

INTRODUCTION

An army is said to march on its stomach—forward progress depending on the mundane realities of preparation and distribution of food. Similarly, a science may be said to progress on its methods, the production of substantive knowledge, basic or applied, depending on the mundane techniques for collecting, analyzing, and interpreting data. In the centennial issue of *Science*, Nobel laureate Herbert A. Simon writes:

> An important part of the history of the social sciences over the past 100 years, and of their prospects for the future, can be written in terms of advances in the tools for empirical observations and in the growing bodies of data produced by those tools (1980: 72).

This is not to say that methodology alone can create or advance science—the most sophisticated method used mindlessly can produce, at best, only pyrotechnics to dazzle the uninitiated. It is the thoughtful development of specialized methods, their careful application to substantive problems, and the thorough and balanced exposition to the lay public as well as to the technically versed scientific community (exposition that stresses the limitations of the methods as well as their strengths) that shed the bright and steady light by which science can make its way forward. Our confidence in our knowledge about the social world depends to a large extent upon our confidence in the research methods employed to secure that knowledge.

It is methods for large-scale social science research that concern us here. Social science research has become a national resource. Its findings are mined to provide insights about social processes useful for both basic research and social policy applications. They inform the creation of policy. Methodological resources developed for social science research are used to design the evaluation of policy and to secure information crucial to governmental decisions. In 1979 some 150 domestic assistance programs used statistical factors (mostly survey data and the Census) to allocate over $120 billion in federal funds—one-fifth of the federal budget (Wallman, 1980). The federal investment in conducting the surveys to gather the data on which these allocations were based is itself considerable, though small in relation to the amount allocated. The combined budgets of the major agencies fielding the relevant surveys were approximately three-quarters of a billion dollars in 1979.

What are these surveys that are so broadly used?

A survey is one means of gathering information about the characteristics, actions, or opinions of a large group of people referred to as a "population."[2] The population might be voters and the information sought might be their opinions of candidates or their vote intentions; the population might be recipients of food stamps and the information sought might be how the food stamps are used; the population might be consumers and the information sought might be whether they intended to purchase a new major appliance within the next year; the population might be the entire United States population of working age and the information sought might be the amount of unemployment. The groups that are interested in the results of such surveys and hence commission them or carry them out vary enormously. Besides agencies of the federal government such as the Census Bureau and the Department of Agriculture, they include commercial polling firms, organizations specializing in market research, university-based research institutes, and state and local governments.

Surveys can be classified by whether they involve only one interview or repeated interviews with the same respondents. A methodologically influential one-time (or cross-sectional) survey was the Equality of Educational Opportunity Study, which collected data on some 570,000 school pupils, 60,000 teachers, and 4,000 schools. The study asked questions about the effect of school facilities, teacher characteristics, and home situations on students' educational performance. Its analyses and reanalyses, discussion and controversy generated much heat but also shed much methodological light on succeeding studies (see Mosteller and Moynihan, 1972). Surveys that repeatedly interview the same respondents are called longitudinal or panel surveys. They have major advantages over one-time surveys in their ability to follow individual changes over time and thus illuminate the social processes that are at work. Thus the Panel Study of Income Dynamics (Morgan, 1977) can describe those Americans who are persistently poor (that is, below the poverty line year after year), and contrast them with families who dip below the poverty line only once in a decade of interviewing. Similarly, the Parnes

Study, also called the National Longitudinal Studies (Bielby et al., 1977), can investigate the long-term effects of chronic teenage unemployment on future labor force participation.

Surveys can also be classified as to whether they are seeking information about a system "as it stands," perhaps in order to establish a baseline against which to measure the effect of a policy change, or about the impact of a program change after it has been implemented, either in full or on an experimental basis. The Current Population Survey (CPS), carried out each month by the Census Bureau to measure, among other things, the amount of employment and unemployment, is an example of a survey measuring a current condition, as was the survey conducted to measure equality of educational opportunity. Surveys designed to measure the impact of a program or policy change can be roughly divided into those embedded in quasi-experiments and those embedded in true social experiments.

Quasi-experiments[3] using surveys fall into two broad classes. The interrupted time-series design collects data from the same people or from the same population for a considerable period of time before and after some policy change or intervention occurs. The data from the "before" period give some indication of the trends in the phenomenon and its variability in the absence of any intervention. These provide a yardstick with which to measure the effect of the intervention and to gauge whether a discontinuity in the time series at the point of intervention represents a real change. This use of surveys has had little large-scale application to date because no sufficiently long, valid, and credible time series have existed. The massive data collection and documentation efforts detailed in the present paper may well yield such time series for future use.

The second kind of quasi-experimental use of surveys seeks data from groups in the new program and also from control groups. The control groups are designed to be as like the program groups as possible on the variables that are expected to influence responses to programs or to be important as alternative explanations for changes in the program groups. For example, the study of the impact of Project Head Start, conducted by the Westinghouse Learning Corporation and Ohio University under contract with OEO in 1968–1969, used 1,980 first-, second-, and third-grade students from 104 Head Start centers and a matched group of nonparticipating children from the same schools as controls in conducting the evaluation (Granger et al., 1969). The two groups were matched on the key variables of age, sex, race/ethnicity, and kindergarten attendance. The socioeconomic status of the two groups was made as comparable as possible by the use of a statistical technique called analysis of covariance. Small but statistically significant differences on a few of the outcome measures in favor of the full-year Head Start group were found.

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Quasi-experiments are fraught with inferential dangers. A well designed and analyzed quasi-experiment makes every effort to separate the effects due to the program from effects due to other causes. For example, such investigations must always ask whether self-selection to the program by those most likely to benefit from it causes the program to appear more effective than it would be if offered to the general population. Conversely, selection of those most in need of the program may also select those least able to benefit and thus make the program appear less effective than it should. However much care is exercised, such isolation of program effects is never completely possible in quasi-experiments. Thus unambiguous causal statements—bold statements that the program caused the outcome—cannot be made from quasi-experiments.

It is for this reason that true social experiments, the other application of surveys to evaluating the impact of program change or innovation, are mounted. Here a proposed policy innovation is implemented experimentally among a *randomly chosen* group of potential participants, with another *randomly chosen* group serving as a control to evaluate outcomes in the absence of the program. It is the act of randomization that makes the control and experimental groups the same before the program is introduced and thus permits probabilistic assessment of whether any subsequent differences between them are effects of the program.

The earliest of these large-scale true social experiments was the New Jersey Negative Income Tax Experiment, and this was followed by several other income maintenance experiments across the country. The purpose of these studies was to find out whether a government-supplied income supplement to poor people would reduce their incentive to work. The findings indicate that little disincentive is created for primary wage earners, but slightly more exists for secondary wage earners. Other large-scale social experiments have investigated the effects of offering housing allowances and differing health insurance plans.

Surveys in their various forms are one of the tools that Herbert Simon refers to in the passage quoted earlier in this essay as providing a growing body of data. But Simon goes on to say,

> It is perhaps not important that we have more information than our ancestors; it is vitally important that we have better information. A major part of the effort of trained social scientists has gone into improving our techniques for making the kinds of measurements that I have just enumerated [essentially survey data] (1980: 72).

Two key aspects of proper surveys in which methodological advances make possible the gathering of better information are sampling and standardization. A survey is used to obtain information, not from every member of the population, but only from a sample selected using probability methods. If the sample is drawn in a properly random manner (and not haphazardly, for example, or by the use of volunteers or those conveniently at hand), then the results of the survey can be generalized to the population from which the sample was drawn. The second key attribute of a proper survey is that its procedures are standardized—it uses prescribed forms of questions and standardized methods of asking them.

In one way or another, sampling and standardization to obtain valid measurement are the themes of this paper. What are the methods that social scientists and statisticians have devised for making surveys yield better information? Probability sampling methods have a long history of theoretical development, but recently methodological attention has turned to those factors that can destroy the value of information from surveys even when probability samples are employed—problems of nonresponse and mistaken responses. Peeling away the variability originating from these extraneous sources purifies our information, giving us more confidence in its validity.

What are the effects of differing decisions about the standardized procedures for a particular survey? Does it matter whether the interviewing is done in person or on the telephone? Does the form, context, or ordering of questions make a difference in the estimates prepared from the surveys? As research is done to answer these and related questions, we learn more about the validity and generalizability of the information given us by surveys and are more able to improve them.

This paper discusses some of the methods that have been and are being developed to reduce the fuzziness of the knowledge gained from large-scale surveys and experiments. Ideally we should like to go out into the world with a coherent theory of human behavior and a foolproof machine for measuring the effects brought about by our precisely specified causes. But usually our theories are stated only in broad and general terms. We often have only approximate ideas about causality. Our ability to measure effects is limited by the extraneous variability in our measurements brought about not only by the process of sampling but also by the standardization decisions made in any particular case. Our ability to measure effects is also limited by people's insistence on acting like human beings—refusing sometimes to answer our questions, insisting sometimes on their own interpretations of meanings rather than the ones we have in mind, and so on. It is to the separation of these extraneous sources of variability from the actual measurement of the phenomena of interest that we turn as we examine the concept of total survey variability.

In the process we hope to see where new advances will arise. It is difficult (perhaps impossible) to shine a beacon into the future—but if we illuminate the recent past we may perceive the methodological advances that reflect their influential images onto the years ahead.

TOTAL SURVEY VARIABILITY

Although surveys and experiments are conducted using samples of individuals, their purpose as we have seen is to learn more about the broader population from which the sample is taken. That information may range from the answers to such relatively simple questions as "What proportion of the population is female?" through more difficult or sensitive ones such as "What is the average annual expenditure for medical care for members of the population?" on up to such conceptually complicated ones as "What effect on the incentive to work among the members of this population would an income supplement have?" In all cases, it is correct answers to these questions *for the population* that are of interest, not answers that are correct only for the people surveyed, nor answers that are incorrect even for the people surveyed and hence, of course, incorrect for the population.

As the results of surveys become more important for society—for example, as unemployment statistics from the Current Population Survey (CPS) become the basis for distributing federal funds, as citizens' expressed opinions on issues of the day come to shape the platforms (and later the policies) of political candidates, as poll results, rightly or wrongly, become the basis for including or excluding a third-party Presidential candidate from nationally televised campaign debates—it becomes more and more important to make these results as accurate as possible. Efforts to improve the accuracy of surveys (and other data collection methods) focus on the sources of inaccuracies; the underlying assumption is that if such sources can be identified they can eventually be controlled, or at the very least, their effects can be taken into account in the interpretation of results.

To address sources of inaccuracy many investigators use the concept of total survey error and several models have been developed to operationalize the concept (e.g., Lessler, 1979; see Mosteller, 1978 for a simple technical exposition of the Census Bureau Model). We shall use the blueprints of these models to guide our exploration of the effects of variability in surveys.

This is the first of many times in this paper that the notion of a model appears. What is a model? It is a formal expression of a theory or a set of causes that the proposer regards as having generated the observed data. In statistics such a model is usually expressed in symbols—and thus is a mathematical model. While architects and engineers construct scale models of their projects, the model of the statistician is not this sort of scaled-down but concrete representation of an object. It is a model of an abstract process, usually greatly simplified, and used frequently to explore how varying the inputs affects the outputs of that process. A better analogy than the model of the architect or the engineer is the animal model of the biologist. In a toxicological study using an animal model, the assumption is made that the vital processes of the animal are sufficiently like those of a human being that information about the drug's effects on the animal will have some value in understanding its effects on humans. There is, however, no assumption that the animal is "just like" a human being. Similarly, a statistical model is not "just like" the process it represents; rather it abstracts out the most salient elements of the process for study.

Statistical models serve as the core of surveys and experiments. The income maintenance experiments were guided by a model that suggested that earned income depends on the amount of income supplement and other variables. The purpose of the experiments was to find out how this dependence is expressed. Thus certain quantities in the model (e.g., amount of income supplement given) were known for each participant. Other quantities in the model, the parameters, were unknown, and the purpose of the experiment was to estimate them. Does doubling an income supplement reduce earned income by one-third? By one-half? More? Less?

It is largely through the proposing, estimating, testing, refining, re-estimating, retesting, and re-refining of models that social science, its methods, and its applications advance. For example, the massive systems of structural equations that model economic processes are the backbone of econometrics; less ambitious structural equation models are used to model smaller social processes. We shall encounter models of labor force participation, marital dissolution and other processes in this paper, but now let us return to a specific kind of model, that of total survey error.

Total survey error models partition the total variation in survey responses into several components that can be studied separately. These components include sampling variability, response effects, nonresponse effects, and their combinations. The goal is to measure and control the total error by providing a mathematical framework for examining separate sources of error. When a real survey is evaluated using the concept of total survey error, the effect of each component is gauged, and then the separate effects are synthesized to arrive at a statement about the accuracy of the entire survey. Similarly, we will examine in turn the major components of total survey variability: sampling variability, response effects, and nonresponse effects, and then look at some progress being made in synthesizing these ideas in measuring the accuracy of surveys.

SAMPLING VARIABILITY

For concreteness in defining sampling variability or sampling error, let us think about estimating the average income for a population from a fully realized probability sample. (For a probability sample everyone on a list, called the "frame," which defines the population, has a known non-zero probability of being included in the sample and all samples have known probability of being chosen. The probability sample is fully realized—in this case—if all people chosen for the sample respond with data on the item asking for income.) Different samples would, of course, include different people, and thus would be likely to yield slightly different results when average income is calculated. Conceptually the measurement of this variation over samples is the measurement of sampling error. For a particular sample, sampling error is defined as the difference between the estimate of the average income of the population derived from the sample and the true average income of the population that would have been obtained if every one listed in the frame had been asked the same question about income at the same time that the people in the sample were asked it. Clearly the size of the error in any given sample is unknown—if the true population average income were available for comparison, there would be little point in carrying out the survey in the first place. Nevertheless, the variability associated with these errors over all possible samples is known from statistical theory and it can be estimated from the variation in a particular set of sample data and the size of the sample. In particular, as the number of people in the sample (n) increases, the probability that many commonly used sample statistics (sample average income in our example) will be near to the population parameters they are designed to estimate (population average income, in our case) becomes larger. In fact, in simple random sampling, the standard error, a customary measure of sampling error, decreases proportionally to $1/\sqrt{n}$.

Thus, suppose the Current Population Survey (CPS) questioned a simple random sample of 400 people (although CPS actually uses much more elaborate sample designs and questions many more people). If the unemployment rate was found to be 10%, then the estimated standard error would be about 2 percentage points. Further, in 95 cases out of 100 the results based on the sample would differ no more than 4 percentage points in either direction from what would have been found by interviewing all eligible adults. If, however, CPS questioned 40,000 people and still found the unemployment rate to be 10%, then the estimated standard error would be reduced by a factor of ten as would the length of the "95% confidence interval" described above.

NONSAMPLING VARIABILITY

But all this assumes an ideal world—among other things it assumes that the frame is an accurate representation of the population to which we want to generalize, that everyone chosen for the sample provides data on income, that the researcher and the respondent share the same definition of "income," that respondents remember correctly and tell the truth, and that nobody makes a mistake in copying down the answer. It is to these nonsampling errors that much interest has recently turned, as results of surveys are taken seriously by the public and policymakers, for in some ways they are harder to understand and control than sampling errors. They cannot, for instance, be decreased just by increasing the size of the sample; as James A. Davis (1975: 42) has put it, "$\sqrt{n}$ wrongs do not make a right."

Nonsampling variability or errors can be subdivided into nonresponse variability or errors (people are left out of the frame, left out of the sample, or do not answer specific questions) and response or "measurement" variability or effects or errors (answers are obtained, but are in some sense "wrong"). We will first consider response errors, a problem that has attracted a good deal of attention in recent years.[4]

Response Effects

Different types of questions are asked in surveys. There are factual or behavioral questions (How old are you? Have you ever been arrested?) for which there is a "true" answer that can, at least in theory, be ascertained for checking the survey response against. At the other end of a scale of concreteness are attitude questions (Do you feel that the President's policies are sound? Would you install insulation in your home if fuel oil prices tripled?) for which there is no external source of a "true" answer. There are continuing debates about whether the concept of "true" answer is even applicable in such cases, and an extensive literature on the match—or lack of match—between expressed attitudes and actual behaviors; see, e.g., Deutscher, 1973. In addition, there are questions that are indeed behavioral—Have you been the victim of an unreported crime this month?—for which no easy outside verification is possible. For current purposes a distinction between factual and attitudinal questions is helpful. With factual questions we may certainly speak of response "errors" when the answer in the survey does not match a publicly recorded fact, while with attitude questions we should speak of response "effects" if two different methods in a survey produce two different answers. That is, if a higher percentage of respondents answers "yes" to the question "Do you agree with the President's policies?" than answers "no" to the reversed question "Do you disagree with the President's policies?" we have a response effect attributable to question wording.

Three broad classes of response effects can be identified (Sudman and Bradburn, 1974): those originating with characteristics of the respondent, those originating with characteristics of the interviewer (or with the interaction between characteristics of the interviewer and those of the respondent), and those originating in the social situation of the interview. This three-fold division will be followed here, although the categories and the variables within them interact. For example, a question form that gives valid data in a face-to-face situation may be inappropriate in a mail survey.

Respondent Effects Differences in respondent characteristics, in general, ought to create real response differences, not ones that might be called "errors." Thus the whole point of a survey, for example, might be to find out if respondents who differ on whether they live with a spouse or live separately also differ in income. Respondents may also possess other characteristics that predispose them to give particular sorts of responses, such as a need for approval, a propensity to acquiesce, or a wish to give socially desirable answers. These predispositions, unrelated to the content of the researcher's question, are called "response sets." Thus, if unmarried heads of households tend to give more socially desirable responses than do married ones, they might exaggerate their income and the true relationships between marital status and income would be obscured. Measures of such a "response set" are hence often included in questionnaires so that their impact can be controlled. But some recent research indicates (Bradburn et al., 1979) that "response sets" may not be artifacts to be eliminated but real personality traits. People who score high on these measures seem to live in limited social environments. They report low levels of behaviors such as sociability, drinking, intoxication, and marijuana use, not because they "are manipulating the image they present in the interview situation, but because [they] have different life experiences and behave differently from persons with lower scores" (p. 103).[5]

Memory is another respondent variable. In factual questions, a respondent must be able to remember correctly in order to give an accurate answer. Two kinds of memory errors can be distinguished: forgetting, and what has come to be known as the "telescoping" of time. In the latter, events, purchases, or victimizations, etc. are reported as happening more recently than they actually did. (This moving of events to more recent times is the usual meaning of "telescoping"; there is some evidence, however, that telescoping may sometimes move events into the more distant past.)

These phenomena work in opposite directions in producing response errors; forgetting leads to underreporting the number of events in a time period, and telescoping typically leads to overreporting. Forgetting can be minimized by using such memory jogs as "aided recall" (perhaps better called recognition) in which the respondent is read or shown a list of the events that may have happened, and asked to indicate with a yes or no answer whether indeed they have, but this may increase telescoping. The encouragement of respondents to take the time to find records of expenditures on such items as health care and home improvements offers increased accuracy and controls telescoping, but is of little use when records are fragmentary or nonexistent.

To control telescoping a technique called "bounded recall" has been useful in panel studies where respondents are interviewed repeatedly (Neter and Waksberg, 1964). At the start of the second and subsequent interviews, respondents are reminded of what they have previously reported and asked what has occurred since those events. Clearly the interviewer needs an easily available and extensive fund of information on the respondent for this technique to be used conveniently, and in this connection Computer Assisted Telephone Interviewing (CATI—see below) offers tremendous possible benefits. As the length of time between interviews increases, the amount forgotten increases, but the amount of telescoping decreases; conversely, as the amount of time between interviews decreases, telescoping increases and forgetting decreases. This relationship suggests that there might be an optimum spacing between interviews so that the effects of the two phenomena tend to cancel out. (See Sudman and Bradburn, 1973).

Problems with faulty memory can be avoided by asking people to keep diaries of their time use. This approach has been employed in basic research on participation in labor both in the home and outside it (e.g., Berk and Berk, 1979, and the Time Use Survey being conducted at the University of Michigan, see, for example Stafford and Duncan, 1979; Hill and Juster, 1979). Government surveys by the Census Bureau have used expenditure diaries to investigate purchase of small, easily forgotten items and these data are used by the Bureau of Labor Statistics to help decide when items included in the Consumer Price Index ought to be revised (Hoff and Thompson, 1980). Gasoline purchase diaries have been used by the Energy Information Agency to supplement the data gathered from the residential energy consumption survey (Thompson, et al., 1980). But diaries are costly, possibly incomplete, and respondent cooperation is difficult to obtain and often deteriorates with time (Kalton and Schuman, 1980).

Some of these problems can at least be addressed. For example, incentive payments have increased the completion rate of diaries (Thompson, et al., 1980), and tape recording can be effective for groups who may have difficulty writing diaries (Sudman and Ferber, 1971). Another approach is to employ electronic "beepers." One group of researchers gave a sample of adolescents these electronic paging devices through which signals were transmitted at random times (Csikszentmihalyi, Larson, and Prescott, 1977). The youths were quite cooperative in pausing in their activities to fill out a brief questionnaire about what they were doing, with whom, and how they felt about it. (Most time was passed watching TV, or in conversation with peers; only 18% of the adolescents' time was spent studying or working.) This seems a technique with wider applicability and has also been used by the Michigan Time-Use survey, where it was found to give results comparable to those obtained by more usual diary methods.

Interviewer Effects The second sort of response effects are those due to interviewer characteristics or to the interaction of those characteristics with those of the respondent. The change of the U.S. Census after 1950 to mostly self-reporting came about because analysis showed that enumerator effects, while not themselves terribly large, constituted a major part of the total variability of the Census.

A recent review of the literature (Sudman and Bradburn, 1974), however, found evidence of only weak effects in this category. Matches between interviewer and respondent on such characteristics as gender or race tend to affect only those questions that relate directly to the matched variable. Thus Blacks tend to give more militant answers to Black interviewers than to white ones—raising the question of which answer is closer to the "true" attitude or behavior. When such an interaction is thought to be important, the sample can be split between matched and unmatched interviewer-respondent pairs and any response effects that arise be reported as part of the data.

Interview Effects Far more important than the previous two categories in creating response effects are variables having to do with the task confronting the respondent and interviewer, and with the social situation in which they find themselves.

Comprehension and communication are the first interview variables, for the investigator and the respondent must understand the question and the possible answers the same way. Some startling examples of misunderstanding have been reported (Kalton and Schuman, 1980). Respondents ignored a carefully worded definition of "a room" when reporting on the number of rooms in their home (after all, they know what a room is, and nobody has to tell them how to count). And only one of 246 respondents to a question of "What proportion of your evening viewing time do you spend watching news programs?" could specify how to work out the proportion. (Perhaps someone does have to tell respondents how to do complicated counting.) Fitting question wording to respondents' understanding, asking for clarification, and asking parallel questions with consistency checks move in the direction of improving comprehension and communication.

Mode of presentation is a second interview variable. Although the popular image of a survey taker is probably that of an earnest female interviewer ringing the doorbell of one of the chosen, in many surveys no interviewer appears at all. Some are conducted by mail, with the respondent filling out the questionnaire alone, and many are conducted by telephone. Mail and telephone surveys are less expensive than those conducted in person, so it becomes important to find out whether they produce differential response effects. No method has been shown to give clearly superior results for all kinds of questions (Sudman and Bradburn, 1974).

There are essentially no differences between telephone and in-person modes for nonsensitive questions (Groves and Kahn, 1979), nor even on somewhat sensitive ones where external validity checks are possible. For example, while 57.1% of the noninstitutionalized U.S. population actually voted in the 1972 Presidential election, overreporting of voting occurred at almost the same level among those interviewed in person and those interviewed by phone in the Groves and Kahn study (66.6% and 69.1% claimed to have voted in the two cases). There is some evidence of greater validity on sensitive questions about such matters as minor lawbreaking in self-reporting mail forms.

Telephone interviews have to give up the visual aids often used in face-to-face interviews; for example when the respondents are handed a card and asked to choose a response category. This procedure allows respondents to say a letter rather than directly state an income in dollars to the interviewer. But some researchers (Durako and McKenna, 1980) have found it possible to mail out visual aids in advance of an appointment for a phone interview. Only small differences in distributions of answers from the two modes resulting from the lack of visual aids have been found.

Open ended questions (where the respondents must answer in their own words) are answered differently on the phone than in person; by phone, answers tend to be shorter and there tend to be fewer multiple answers. In an experiment done in connection with the National Crime Survey (NCS), respondents who were interviewed mostly by telephone reported themselves victims of fewer small thefts than those who were more often interviewed in person. The effect was strongest for males and those between 25 and 49 years old. Thus a switch to telephone maximization for NCS would change comparisons between population subgroups (Woltman, Turner, and Bushery, 1980).

Idiosyncracies of particular interviewers tend to have more effect in phone surveys because each interviewer does more interviews (Groves and Magilavy, 1980). Mail and telephone interviews also sacrifice traditional interviewer skills: recognizing puzzlement from nonverbal cues and giving off reassuring nonverbal messages in return; being able to code the ethnicity and social class of respondents; and being able to report on distracting influences present at the interview that may have response effects (for example, victimization by a member of one's family is unlikely to be reported while that family member is present). Telephone interviewing, at least in single stage procedures, also sacrifices the ability to match the gender and/or race of the interviewer with those of the respondent, but as we have seen, lack of such matching produces response effects only on the questions to which such attributes are most salient.

One mode of presentation tends to increase anonymity because it never forces respondents to tell whether or not the sensitive question has been answered, and hence ought to decrease response effects. The randomized response technique (Warner, 1965) requires a respondent to do some kind of randomization to determine whether the sensitive question or an innocuous one is to be answered. Simple probability calculations then give an estimate of the number in the sample who agreed with the sensitive question, without revealing which respondents did so. The technique has been found to reduce distorted responses to socially undesirable questions (that one would expect to be underreported), but to be ineffective in reducing distortion to questions dealing with socially desirable behavior (that one would expect to be overreported) (Locander, Sudman, and Bradburn, 1974).[6]

Still another mode of presentation designed in part to increase anonymity and hence increase response accuracy is called network sampling. Individuals, rather than being asked about their own behavior or characteristics are asked about behaviors or characteristics of their friends or relatives (Sirken, 1975; Sudman, et al., 1977).

In summary, the usual modes of presentation introduce few response effects on nonsensitive questions; with more sensitive questions, however, the more anonymous modes seem to elicit more valid responses. Further, the shortness of telephone interviews may permit respondents to decide that some incidents are too trivial to mention. The Current Population Survey (CPS) uses both telephone and in-person interviews, and there is little or no evidence that these different modes create response effects on statistics of employment and unemployment, although further research on the topic has been called for (Brooks and Bailar, 1978). The 1980 census experimented with telephone rather than in-person follow-up for a sample of those who did not mail back the census forms in order to compare the modes of completeness of data, costs, and interviewer attrition (Bailar and Miskura, 1980); the results of this trial are not yet in.

Even while investigators are attempting to understand the response effects connected with "traditional" modes of interviewing, within the last decade a new mode has been developed, and the response effects that it may introduce must take their place on the research agenda. This new mode, which may turn out to be a major innovation in interviewing, is Computer Assisted Telephone Interviewing (CATI).

Rather than reading from a printed questionnaire, the interviewer reads questions from the screen of a Cathode Ray Tube (CRT) attached to a computer terminal, and records answers by typing them in on the keyboard of the terminal. Because a computer is involved, CATI offers greatly increased flexibility from beginning to end of the interviewing process. Interviewers can be presented with sample telephone numbers to be called in random order, callbacks can be automatically scheduled, and respondent selection probabilities can be altered as interviewing progresses (Roshwalb, Spector, and Mandansky, 1979; Dutka and Frankel, 1980).

In a printed questionnaire, instructions to the interviewer about which questions to ask of which respondent can get very complicated very quickly, and it has been common practice to allow no more than four levels of contingency (e.g., ask this question only of males, over 28, with children, and no military service). In CATI, because the computer is programmed to do this "branching," as many as 17 levels of contingency have been used (California peak load pricing experiment; Lebby, 1980). Contingent questioning can be used to explore successively more sensitive areas, thus providing more information and less nonresponse, with respondents typically dropping off only after supplying at least some information. Information from earlier in the interview can be introduced in questions later in the interview, as can material from earlier interviews with the same respondent if the study is longitudinal. Question wording can be tailored to the respondent, for example, to the appropriate level of education, thus bringing the meaning of the question as intended by the researcher and as understood by the respondent into closer correspondence than is usually possible with a structured questionnaire.

Most systems for CATI can also do calculations to provide sample statistics as data arrive, and sample sizes can be determined sequentially. Errors are reduced because the operations of data coding and entry are short circuited, and because most systems are programmed to recognize wild or inconsistent values and request correction on the spot.

CATI may well offer the opportunity to test much of the conventional wisdom of professional survey researchers (Freeman, 1980). For example, because question order can be easily, independently, and automatically randomized, and records automatically kept of which respondents receive what order, experiments on question ordering can be carried out routinely, as can experiments on the effect of the order in which the interviewer reads the possible responses to questions.

Switching from hard copy questionnaires to CATI creates some problems: flexibility that is needed but not anticipated by the system designer is difficult to achieve; interviewer training differs from what is traditionally done; and currently systems from different installations are incompatible (Groves, et al., 1980; Shanks, 1980). It is not clear at this time whether these are the early growing pains of a new technology or more permanent faults.

There is speculation that CATI, if used imaginatively, can represent a quantum leap in technology. For example, there has always been a tension in the construction of survey instruments between the canons of good measurement which dictate multiple indicators—as in a battery of questions measuring a psychological trait—and time and respondent patience constraints that dictate the use of single questions or at most a few indicators. One could conceive of asking a question or two to determine the *approximate* scale location of a respondent (e.g., toward the conservative end of the scale) and then using the flexibility of CATI to choose further questions tailored to particular respondents and useful in placing them at more precise scale locations. Screening in telephone interviews on routine demographic and other characteristics will, with some regularity, turn up respondents that are of special interest for policy or other reasons, e.g., who are members of sparse groups (young Chicanos, sufferers from a rare disease). If interviews are on-going under CATI for several studies, it would be possible to program the system to introduce a module of questions pertinent to the research concerns about the "sparse" group into an on-going interview whenever a member of that group is found, thus gradually gathering a sample of sufficient size for generalizing. (But see the discussion below of the response effects due to questionnaire context; such problems may make data gathered in this way less attractive than they seem at first glance.) Finally, the notion of compressing CATI into a microprocessor so as to make the "questionnaire" portable and playable through a TV screen in a respondent's own home has been suggested (Lebby, 1980; Shanks, personal communication). Such a procedure might capitalize on respondents' pleasure on being informed that a computer is involved in the interaction; it might also be a device for assuring confidentiality of survey data, for respondents could interact with the CATI system without the intervention of the interviewer, presumably secure in the knowledge that no one would see their identified data.

Question form—the art of question writing and questionnaire construction—has been described for years in texts, manuals, and word-of-mouth instruction. The scientific study of response effects produced by these variables also has a long history, but the more recent availability of survey archives and the increasing seriousness with which survey results are regarded have inspired a new flowering of research.[7]

Open-ended questions ("What is your opinion of the President's handling of the crisis in Iran?") have long been believed to give more accurate information on respondents' attitudes than closed-ended ones ("Do you think the President's handling of the crisis in Iran is excellent, fair, poor, or terrible?"). Current opinion is that neither form has a clear superiogity overall. Open-ended questions are clearly needed, however, in at least two situations: when salience of issue to the respondent is being investigated, so that the respondent's words indicate the thought invested in the topic; and in the early stages of questionnaire construction, when the freely chosen wording of pre-test respondents is crucial to the construction of response categories to be used in the closed questions for the bulk of the survey.

Long questions are in bad repute for slowing down the pace of the interview and supposedly confusing respondents. Recent studies, however, have experimented in lengthening questions by adding redundant or irrelevant material without complicating them. (For example, instead of "What health problems have you had in the past year?" one might say "The next question asks about health problems during the last year. This is something we ask everyone in the survey. What health problems have you had in the past year?") The result is sometimes a longer answer from the respondent and frequently a more accurate one, in the sense that more events are reported. Longer answers seem to be given even for shorter questions when they are mixed in with long ones in a questionnaire (Cannell, 1977). Perhaps the interviewer is both modeling and reinforcing longer answers by asking longer questions.

It has long been believed that although changing the form of the question may change the distribution of respondents among the response categories (e.g., if one asks "Are you in favor of ERA?", instead of "What is your opinion of ERA, are you in favor, neutral, or opposed?" one is likely to get different percentages of responses reporting themselves in favor of the amendment), the correlation between answers to such a question and other variables would not change with the form of question. This is the notion of "form-independent correlation." Recently as part of a continuing program of research on question effects, questions on attitudes about foreign governments sometimes included an option of "no opinion" and sometimes required respondents to volunteer that they had no opinion if that were the case. Not only did the percentage of respondents reporting "no opinion" increase when the alternative was explicitly offered, as expected, but the correlation between items asking opinions of different foreign governments changed as well (Schuman and Presser, 1978). Similarly, the correlation between change in interest in religion and change in attendance at religious service appeared stronger when the two questions had similar response categories (Duncan and Schuman, 1980).

The context in which a question is asked—the ordering of questions, inclusion of other questions, the very arrangement of a questionnaire—can produce response effects. The ordering of the questions within a questionnaire may produce effects through several mechanisms (Sudman and Bradburn, 1974): (1) Order may influence the salience of topics (with low salience topics being most affected because it is easier to increase salience than to reduce it); (2) If there is overlap between questions, respondents may be reluctant to be redundant and repeat details they have given earlier; (3) An urge to consistency might cause answers to earlier questions to influence later ones—respondents express less confidence in institutions when such questions are asked after ones on political alienation than when they are asked before (Turner and Krauss, 1978); (4) Later questions in a lengthy questionnaire may be answered in a perfunctory manner because of fatigue. In a variant of this problem, fewer incidents of victimization were reported if the questionnaire was structured so that detailed information for each incident was requested immediately after the incident was mentioned than if the respondent was encouraged to list all incidents of victimization before being asked to describe any one in detail (Biderman et al., 1967); and (5) The opposite of a fatigue effect may occur, with the rapport between respondent and interviewer growing as the interview proceeds—thus, sensitive or threatening questions are often placed late in an interview when rapport is presumably high.

In particular, questionnaire context may well affect responses to questions that have few everyday implications ("What is your opinion of U.S. foreign policy?" vs. "How many children do you plan to have?"), to questions with ambiguous response categories (very happy, pretty happy, vs. one child, two children, etc.), and to questions on somewhat vague or amorphous concepts (attempted assault as opposed to actual assault as forms of victimization; Turner, 1980). Several experiments, across survey organizations but at approximately the same time, are currently addressing these context effects.[8]

In addition, light could perhaps be shed on the problem of context dependency if investigators were to switch focus from the *question*, asking which forms are susceptible to contextual effects, to the *individual*, or perhaps type of individual, asking what sort of person is affected by context. Is it the better- or more poorly-educated person whose thinking changes with the context in which a question is asked; those who have given the matter a great deal of thought, or those who have not yet thought deeply about the issues? Of course, these variables are more difficult to study than those relating to types of questions, for variables relating to individuals (other than demographic variables) are most logically studied in a test-retest design, which is difficult to administer, and has artifactual problems of its own, rather than the typical split-ballot technique used to investigate the effects of context variations over aggregates of people.

The very appearance of a self-report questionnaire may produce response effects, especially inaccuracy. The 1980 Census experimental program sent out variants of the usual Census form that were "people-oriented" in contrast to the standard form which is "computer-oriented" (Bailar and Miskura, 1980). These forms, because of the additional data transcription costs and risks of error they entail, will have to show major advantages over the machine readable questionnaire in mailback rate and data completeness if their use is to be justified.

Current Research Prospects The comparison between modes of interviewing is an area where we can expect more research, and perhaps more definitive results over the next few years. In particular, the advantages and drawbacks of CATI will be explored. Systems are currently being used or developed in surveys by commercial firms, by university-based research centers, and by the U.S. Bureau of the Census (Nicholls, et al., 1980).[9] The branching flexibility of CATI will produce data that are themselves hierarchical. Statistical methods designed to deal with such data sets do not yet exist; we would expect that the existence of the data sets would stimulate development of the methodology.

The work of the Panel on Survey-based Methods of Subjective Phenomena of the Committee on National Statistics will go a long way in charting the course of future developments in the study of response errors in attitude questions. Other work promises to bring the insights of cognitive psychology on the functioning of human memory and coding abilities to bear on problems of question formulation and understanding of respondents' answers.

Nonresponse and Nonparticipation Effects

We know that those who do not answer some or all questions in a survey, who drop out of an experiment, or who are never home to an interviewer, are different from those who answer, remain, or are at home in terms of refusing to answer, dropping out and being away from home. It is likely that they are different in other ways as well. And if these ways include differences in the variable(s) the study is trying to measure (say, income or political opinion), then the results of the survey will be biased. If, for example, the estimate of the average income of the population (or percent in favor of a candidate) is based only on data from those who responded, it could be very different from what would have been estimated if the nonrespondents had also answered. (Recall that the answer for the complete sample may incorporate sampling and response error.)

It is useful to distinguish between "unit" nonresponse and "item" nonresponse. In unit nonresponse, entire sets of data are missing for potential respondents because they were missed in the field (e.g., were never at home), were missed in the frame (e.g., for data being collected by telephone surveys, did not have telephones), or refused to participate. Item nonresponse occurs when an individual's answers to some parts of a survey instrument are missing, or are inconsistent (e.g., wage income plus interest income plus income from other sources is greater than total income), and so are edited out in the data cleaning process and must be replaced by a more consistent set of answers.

There is reason to believe that both item and unit nonresponse are high and getting higher, even in surveys under government sponsorship. Refusal rates for the Current Population Survey (CPS) have risen from 1.8% in 1968 to 2.5% in 1976; for the Health Interview Survey (HIS) from 1.2% to 2.1% in the same time period (Panel on Privacy . . ., 1979). These numbers are particularly worthy of concern when we take into account that both these surveys are conducted by the U.S. government, that extensive and increasing efforts are mounted to reach respondents initially not found at home, and that each 1% of the American population represents over two million individuals. The problem is not confined to the United States, however. Results of the Swedish government Labor Force Survey show refusals have risen from 1.2% in 1970 to 3.9% in 1977 (Dalenius, 1979).

Even the U.S. Census, to which responding is required by law, is not immune. In the 1970 U.S. Census, data had to be imputed (filled in) for such items as age (4.5% of the respondents) and total family income (for 20.7% of families) (Bailar and Bailar, 1979). It is estimated that the 1970 Census undercounted by 2½% (or about five million people) even after adjusting the count whenever there was a shred of evidence to do so. (Housing and Post Office checks by the Census Bureau on a sample basis showed that there were some occupied buildings for which no residents were counted. This made it possible to adjust the count by adding some five million people who had not filled in census forms before that estimate of the undercount was calculated.) The problem of undercounting or nonresponse in the 1980 Census is now a major source of legal challenges.

Given the conflicting pressures it must face, it is remarkable that the Census can be as accurate as it is. Many people believe that responding should be made voluntary. Nevertheless, there is both broad support and legislative mandate for allocating funds to localities on the basis of the proportion of the residents falling into certain categories. Further, some of the residents in those very categories strongly prefer not to be counted, for such reasons as the receipt of illegal income, or illegal immigrant status. Deciding whether indeed we want the count as accurate as possible or whether other values have higher priority seems to be an issue.

Nonresponse is an even greater problem in nongovernmental surveys. In surveys with varying sponsorship, dealing with varying populations, and using varying definitions of nonresponse, one study found nonresponse ranging from a low of about 5% to a high of about 87% (Panel on Privacy . . ., 1979). If the current trend continues, the problem of nonresponse is likely to persist and even to be exacerbated. Without substantial efforts to curb nonresponse, response rates in major national data collection efforts are likely to continue to drop so that survey results will become practically and scientifically useless. Thus the vigorous scientific activity being devoted to developing methods for reducing nonresponse, for adjusting it when it does occur, and for properly analyzing the resulting data are crucial to continued good quality data from surveys.

Reasons for Nonresponse Several reasons for the rise in nonresponse have been suggested, and some have been investigated. Apathy, lack of belief in surveys, and reactions against sales pitches masquerading as surveys might well lead to refusals. Further, distrust of investigators and concern with privacy and confidentiality, perhaps heightened by requests for informed consent (Dalenius, 1979), may well produce both unit and item nonresponse. In an experimental survey by Singer (1978), a promise of confidentiality consistently decreased item nonresponse to sensitive questions. A similar experimental survey conducted under the auspices of the Panel on Privacy and Confidentiality as Factors in Survey Response (1979: 116) found steadily decreasing percentages of unit nonresponse (both refusals and total noninterviews) with increasing assurances of confidentiality, but the differences were small. (Perhaps the differences were small because the Census sponsorship of the study produced relatively low nonresponse rates, regardless of promised level of confidentiality.) We can expect more research on the causes of refusals and other nonresponse.

Nonresponse in the sense of noncoverage in the frame can be unintentionally introduced in the design stage (Morris, 1979). For example, a design based on imperfectly measured variables or those that are subject to random change will exclude some part of the population. Consider a frame confined to "low income" people: those whose incomes in the critical year were "accidentally" higher than their permanent incomes will be excluded. (Of course, those with "accidentally" lower incomes will be mistakenly included.) Similarly, a frame that is constructed to tap large concentrations of a target group will often miss atypical members of that group: thus, a frame using low income census tracts to reach low income people would miss low income people living in high income tracts.

Reducing Nonresponse Certainly the preferred method of dealing with nonresponse is to keep it from happening, though such procedures are often very expensive. Thus a battery of techniques has been developed with the general aim of encouraging the chosen respondents to participate, or of systematically substituting other informants or respondents in the field.

Encouragement to respond takes many forms. In designing field operations, stress is placed on training interviewers to understand the purpose of the study and to establish rapport with respondents. Callbacks are routine (though expensive; survey organizations estimate that with a 75% response rate, the first 70% accounts for 50% of the cost, and the last 5% accounts for the other 50%). Especially for surveys under government auspices, enlisting the cooperation of local governmental bodies and professional organizations has proved helpful (Morris, 1979). Incentives to respondents seem to be somewhat useful. (In the Health Insurance Study, however, despite governmental backing, apparently substantial benefits, and belief in the value of the study, 19% of the invited households refused to participate.)

At the same time, extreme efforts to decrease nonresponse may degrade the quality of the data. Some hard-to-locate respondents can be found with extra effort, and the inclusion of their data will increase the response rate and probably the accuracy of the estimates. Those who refuse to participate but are pressured to do so against their will also increase the response rate but perhaps at the expense of the validity of the estimates. For example, in one study the inaccurate reporting of hospitalization by such hard-core nonrespondents caused the overall estimates of hospitalization rates to be worse than if these respondents had never been questioned (Cannell et al., 1978).

Some nonresponse can be "defined away" by permitting others to answer for an individual, or by substituting for respondents. In household surveys, adults are often permitted to act as informants as to the activities of other family members as well as respondents as to their own activities. While this approach is primarily a money saving technique for reducing callbacks, it also reduces nonresponse. In the Charlotte, North Carolina pretest of the National Health Interview Survey, for example, it was found that 50% more callbacks were required when each member of a family had to respond personally than when the rules were relaxed to let related adults respond for those absent (Nisselson and Woolsey, 1959). This sort of proxy reporting has been extended outside the household in network sampling.

But there is mixed evidence about the accuracy of this procedure, which may sometimes substitute response errors for nonresponse. In victimization surveys one study (Biderman et al., 1967) found that many more offenses were reported by respondents as happening to themselves than to other members of their families. Another study (Ennis, 1967) reports accurate results for white household informants but underestimates of crime rates when the method was used for Black families.

Evidence for the policy implications of these strategies can be found in discrepancies in the estimates of youth unemployment, currently regarded as a major social problem. On February 29, 1980, the *New York Times* reported that the National Longitudinal Surveys of Labor Force Experience (NLS) had found the 19.3% of white and 38.8% of Black youths ages 16-21 were unemployed in Spring, 1979; at that time, the Bureau of Labor Statistics' figures, based on the Current Population Survey (CPS), showed the rate to be 14.1% and 28% for white and Black youths, respectively. The report, one of the first outputs from new cohorts in the NLS, prepared for the Labor Department by the Center for Human Research at Ohio State University, credited this difference to the fact that youths themselves were interviewed by NLS, rather than other family members such as heads of households as is done in CPS. It would appear that a difference in a methodological procedure increased estimates of the size of the unemployment problem anong youths by about one-third.

Many surveys permit substitution, either at random from a similar group or by propinquity, for sample members who refuse or are unavailable. For example, the National Longitudinal Study conducted by the National Center for Educational Statistics used random substitution of schools, while the Michigan Survey of Substance Use permitted the substitution of households adjacent to the one designated in the sample. Old-fashioned quota sampling permitted interviewers to choose their own respondents as long as "quotas" for each sex, age group, race, etc. were met. No probability mechanism was used. As it is currently done by professional pollsters (with multistage area probability sampling down to the block level and then controls on such variables as gender, age, and employment status), quota sampling can be thought of as an extension of such substitution rules. There is evidence that this "probability sampling with quotas" (Sudman, 1967) produces usable results: when the National Opinion Research Center split its sample for the 1975 and 1976 General Social Surveys between true probability methods and quotas, it found no differences between the two techniques other than a deficit of one or two person households in the quota samples (Stephenson, 1978).

Because assurances of confidentiality tend to increase response rates, and anonymity is the ultimate in confidentiality, many surveys routinely arrange for questionnaires to be filled out anonymously. But anonymity cannot be maintained easily in longitudinal studies requiring repeated contacts, and it is seriously compromised in personal and telephone interviews. Methods to increase confidentiality in longitudinal studies are discussed under that heading. In telephone interviews, respondents may return calls in order to preserve anonymity, a procedure that also purportedly reduces unit nonresponse. Most special efforts to insure confidentiality in telephone and in-person interviews deal with particularly sensitive questions, however, and are aimed at reducing item nonresponse and inaccuracy. Mailbacks of answers to specific questions have been used and in some cases the randomized response technique reduces item nonresponse (Boruch and Cecil, 1979).

Adjustment for Nonresponse Despite the best efforts of survey designers and field staff, nonresponse, both unit and item, frequently occurs and must be taken into account. What then can be done, after the fact, to adjust for appreciable nonresponse? It is logically impossible to do nothing: simply to drop the nonresponding units from the sample is to do something, for any estimation procedures that are then implemented tacitly assume that nonresponders are just like responders and that the results of the survey would not have changed had they responded. Doing nothing implies a very specific but simple model: that the forces that prevented some people from responding are unrelated to the variables of interest, so that the distribution of nonrespondents on these variables is no different from the distribution of respondents. Similarly, more complex techniques for dealing with missing data also require implicit or explicit models of the causes of nonresponse and hence of the distribution of nonrespondents—usually that they are distributed like some subset of the respondents having similar measured characteristics (covariates), but sometimes that they differ from respondents in systematic ways (as would be true if, for example, the probability that people would report their income were proportional to income).

A great number of techniques for dealing with missing data have been developed.[10] Some techniques reweight aggregations of data to take into account missing observations, and others "fill in the blanks," creating pseudo-observations in place of the missing ones. In either case, the analyst must take into account that the data have been adjusted for nonresponse, and that such adjustments affect estimates of the accuracy of quantities derived from the data.

A commonly used means of *weighting for missing data* is called ratio estimation. It uses information derived from other studies to improve estimation. Assume the quantity we wish to estimate is $\overline{Y}$ (for example, the average income for the population), and that it will be estimated by the sample mean, $\bar{y}$ (the average income for those in the sample). Assume we also know that Y is related to another variable, X (say number of people per room in living quarters), for which we know both the mean for the respondents in the sample, $\bar{x}$ (mean number of people per room in the sample), and the mean for the total population, $\overline{X}$, from another source such as the Census. If we then make the additional assumption that the ratio of the mean number of people per room in the sample to the mean number of people per room in the population is the same as the corresponding ratio of mean income between the sample and the population ($\bar{x}/\overline{X} = \bar{y}/\overline{Y}$), we can use this relation to adjust $\bar{y}$ to $\bar{y}' = \bar{y}(\overline{X}/\bar{x})$.[11]

A ratio adjustment for nonresponse was used, for example, to correct for response bias in the 1975 Survey of Scientific and Technical Personnel (Tupek and Richardson, 1978). It was found that large firms were least likely to respond to the survey. The total number of employees in the firms in each size stratum was known from other sources and the ratio of scientific and technical employees to total employees remained constant. Hence it was possible to use the ratio of the total employees in the reporting firms in the stratum to total employees in all firms in the stratum to adjust the estimated number of scientific and technical personnel in each stratum.

In the Health Interview Survey respondents are interviewed face-to-face, and asked, among other questions, whether the household has a telephone. Recently, investigators (Thornberry and Massey, 1978) found that health characteristics differ between households with and without telephones; they developed a ratio estimator that could be used to adjust estimates of health characteristics for the bias arising from noncoverage of households without phones, if the survey were redesigned to be done via telephone. The form of the ratio estimator should be valuable for other, similar surveys. This inquiry represents basic research into the properties of adjustment techniques and their usefulness in varying situations.[12]

Techniques that fill in missing values individually for item nonresponse are called *imputation techniques*. Such techniques assume that the value of the missing item can be estimated from values of other items for that respondent. One such technique uses the other items as variables in a regression function, either derived from the data at hand or available from outside sources. Such a procedure must assume (or fit) a particular functional form of the model of how the missing item depends on the other variables (covariates). For example, one might derive a formula that says "Imputed income in thousands of dollars = ½ (age) + 5 if the respondent is male + 2 if the respondent is white − 3 if the respondent is both black and female − .8 × (number of people per room in respondent's residence)."

In the days before high-speed computers, survey analysts often filled in blanks caused by item nonresponse from tables put together from outside sources. Such a table might specify that if the respondent was a married white female between the ages of 30 and 45 who did not answer how many children she had, she should be "assigned" two children. This so-called "cold-deck" procedure, of course, assigned the same number of children to all missing values for women in a specific marital status-race-age group. With the advent of high-speed computers, more flexible procedures became possible.

These "hot-deck" procedures fill in the missing value for the item from the value appearing for another respondent in the same survey who is "similar" to the respondent with missing data. "Similar" is defined by the variables thought to influence the one missing (e.g., for number of children these might still be marital status, race, and age) and all respondents who are the same on these variables are said to constitute an "adjustment class" (I. Sande, 1979). Hot-deck procedures make no assumptions about the functional form by which the variables defining the adjustment class determine the missing item, only that they do. There are now a tremendous variety of these hot-deck procedures: the simplest uses the value of the item that occurred in the previous unit processed in that adjustment class. Other variations, made possible by advances in computer science, random access and dynamic creation of the adjustment classes, choose a donor within the adjustment class on criteria of nearness on further important variables, or introduce randomness into the process of choice of a donor (G. Sande, 1979).

Care must be exercised when making estimates from data that have been partially imputed because the imputation changes the estimated accuracy of the estimates. Further, the sample size for any item is the number of respondents actually giving data for that item and should not be considered increased by the imputation.

A new idea is a process of multiple imputation (Rubin, 1978; 1979). Here the analyst repeatedly uses an imputation method to fill in missing data. Each time the complete data set is imputed, an estimate is made of the quantity of interest. One can then examine the distribution of these estimates to see if, or how much, they vary with different imputed data sets. If several different assumptions about the "causes" of nonresponse are plausible, a set of multiple imputations might be carried out using each assumption as the model to determine the imputation method, the set of sets of estimates made, and thus the sensitivity of the estimation to the model assumed for nonresponse explored as well. The justification and interpretation of this multiple imputation procedure come from a "Bayesian" technical stance (Rubin, 1978; 1979).

One can think of multiple imputation as a program for investigating the properties of the various methods of imputation in the context of various models for nonresponse or differential response (c.f., Heckman, 1976) using a variety of data sets. Some comparisons of the different methods have already been made (e.g., Bailar and Bailar, 1978, 1979; Cox and Folson, 1978; Ford, 1979). So far we know that there are differences in both systematic and random error over the techniques, but no consistent pattern is yet visible.

Current Research Prospects Nonresponse, its causes, cures, methods of coping, and their properties represent active lines of research. In 1978 several sessions at the annual meeting of the American Statistical Association discussed nonresponse;[13] the Committee on National Statistics has established a Panel on Incomplete Data which held a symposium in August 1979.[14] The Panel is reviewing and comparing procedures used for incomplete data, summarizing theory and methods for field procedures, data processing, and estimation; and plans to make suggestions for reporting surveys so that results of nonresponse can be taken into account. Its report will undoubtedly call for more systematic studies of the performance of imputations, perhaps following Dalenius (1979) in asking for a series of simulation experiments. In such experiments complete data would be artificially subjected to nonresponse mechanisms, and analysts would attempt to estimate the (known) population characteristics and to describe the nonresponse mechanisms. As it becomes more and more obvious that the most rigorous mathematical treatment of the effects of adjustment for nonresponse is only as good as the model of the process assumed to be causing the nonresponse, it seems likely that treatments of the subject, practices, and comparisons between practices will take on a more Bayesian aspect, either formally or informally.

TOTAL SURVEY VARIABILITY REVISITED

Several investigations have examined the accuracy of particular surveys through the synthesizing concept of "total survey error" (or related ideas that examine all possible sources of variability and their impact on estimates made from the data).[15] One major study applied the concept of total survey error to the 1970 Center for Health Administration Studies-National Opinion Research Center national health survey, collecting data on health services use and expenditures (Andersen, Kasper, Frankel and Associates, 1979). Verification data were collected from health-care providers (doctors, hospitals, etc.) to compare with respondents' reports for the measurement of response errors. The effects of nonresponse and of different approaches to imputation of nonresponse were also investigated. One important finding of the study was that conclusions about the differences in health-care experiences between important subgroups of the population (the elderly vs. others; the poor vs. others, etc.) changed very infrequently when adjustment was made for those parts of nonsampling error that could be measured. The magnitude of the differences, however, did change more often. The verification process was a lengthy and expensive one (18 months and accounting for about one-third of the million-dollar cost of the survey), so whether it should be incorporated more regularly into surveys depends on the anticipated changes in estimates that adjustment for error will cause. Probably several more such large-scale efforts in different fields of application will be necessary before such anticipations can be made with any degree of confidence.

"An Error Profile" has been compiled for the measurement of employment by the Current Population Survey (Brooks and Bailar, 1978). Such a profile is related to the concept of total survey error, but is constructed by following the operations of a survey, step by step, from the construction of the sampling frame through the publication of results, pointing out possible sources of all kinds of error, and presenting evidence of their direction and size when such estimates are available. This effort[16] was intended to serve as a model for such profiles for other major governmental surveys, and as a first attempt deliberately chose not to consider such matters as conceptual errors; these matters will probably be addressed in future profiles. Another error profile has been compiled for multiple frame surveys by Norman Beller at the Department of Agriculture. It would seem that this sort of project, while also expensive and time-consuming, will point to gaps in knowledge about nonsampling errors and stimulate efforts to fill the gaps.

The Office of Energy Information Validation of the Department of Energy has been created specifically to understand the error structure of data collection and analysis in this important policy area and to improve practice. Work in that office (1) investigates information needs and whether they are being met by data collection systems, proposing improvement when necessary; (2) carries out studies aimed at validating data, looking at the effects of response errors and of nonresponse and imputation; (3) studies the workings of models used to make estimates and predictions from the data; and (4) examines publications of these estimates and predictions for their informativeness, ease of comprehension, and clarity in explaining the meaning of estimates and the amount of uncertainty they are likely to contain. A self-conscious effort to document procedures used to accomplish these tasks is also under way.

Research Triangle Institute is at work on a taxonomy of errors, as an early step toward the institution of a Survey Design Information System. Such a system (Horovitz, 1980) would store information about specific variables as they have been measured in social surveys, including context of the survey, sample design, wording of questions, error components, and costs. This is a concept even broader than that of total survey error and should serve to standardize survey measures, integrate knowledge of survey error components, improve survey design, and provide a broad base for methodological research.

LONGITUDINAL SURVEYS

How many of the American people are poor? The answer depends on what one means by the question. According to the Panel Study of Income Dynamics, in a single year (1975) nine percent of the American people were below the official poverty line, twenty-five percent were below it in at least one of the nine years before 1976, but only one percent remained in poverty for the entire nine years (Morgan, 1977). These distinctions can make a difference. For example, strategies for effectively assisting the chronically poor are probably very different from those most effective in aiding the temporarily poor; decisions about the magnitudes of the efforts would probably depend on the relative sizes of the two groups.

For our purposes, the crucial point about these differing figures is that they could have been found out (without unduly trusting people's memories) only by questioning the same people repeatedly—that is, by a longitudinal (or panel) study rather than a cross-sectional one. A cross-sectional study could only have estimated the number of poor in the year of the study, giving no data (except those based on fallible memory) on the number of persistently or occasionally poor. The difference is like that between a snapshot of a crowd where we can make some aggregate measure such as the number of people present, and a motion picture in which we can see the aggregate size of the crowd at each moment and also follow the activities of individuals as they leave or enter the crowd over time. The implementation of such large-scale longitudinal studies gained impetus in the early 1960s, corresponding to the start of large-scale social experiments (Kalachek, 1979).

ADVANTAGES OF LONGITUDINAL STUDIES

The distinctive feature of a longitudinal study is that it permits an investigator to follow people (or other individual units of analysis, e.g., families, organizations) over time; this means that data on individual changes, rather than only aggregated movements, are available for analysis. Thus research can focus on process by asking "how" and "why" and often "for whom" such changes occur. For example, in studying life-cycle processes a panel study might address such a question as "Does early unemployment among teenagers and youth represent a transitory phase that many go through with no particular long-run adverse consequences, or does such a period of unemployment lower future earnings and/or increase the proportion of time in later life that an individual is unemployed?"

The aftermath of the 1980 Presidential election provides an example of the use of panel data to illuminate process. The New York Times/CBS poll questioned a large national sample during the week before the election and was able to recontact 89% of the respondents who were registered voters in the few days following the election. The gap between the two major candidates increased by about seven percentage points in the week between polls. But this is aggregate or "net" change. It was actually brought about by some 21% of the registered voters polled who changed their minds (some from Carter to Reagan, some from Reagan to Carter, some from Carter to deciding not to vote, and so forth). Respondents who reported votes different from the ones they anticipated before Election Day were asked for reasons for the change. Thus the poll was able to conclude that "news of the Iranian conditions for releasing the American hostages that broke the Sunday before Election Day was a major element in those shifts, . . . but so, apparently were last minute rejections of Mr. Carter's handling of the economy" (*New York Times*, November 16, 1980: 1).

The existence of large-scale longitudinal data sets has inspired both methodological and substantive research and has drawn attention to the need for developing new methodological tools for their analyses. One example of this is in new applications of mathematical models. These include statistical models that treat time as continuous and thus are more likely to coincide with our theoretical understanding of social processes and more likely to represent faithfully actual behavior than are models that treat time as discrete. People do not change jobs, break up marriages, etc. at specific (discrete) times (such as the time they are asked about their status on these variables). Thus any decision about the proper length of the time chunk to consider is necessarily arbitrary. Weekly is probably frequently enough to observe whether job changes occur—but is monthly frequently enough? And analyses that make these arbitrary decisions differently for use in discrete time models can produce substantively different results. Further, continuous time models are often computationally simpler than discrete time models.

In addition, most human behavior is more complicated than the simplest models need to assume. One discrete time model of employment, for example, would define three "states": employed, unemployed, and out of the labor force. It would then need to assume that the chance of a person being in a particular state in the next time period (e.g., month) depends *only* on which state that person is in during this time period. Past history, including amount of time in current state is taken to be irrelevant. (This is called a Markov model.) Clearly the world is more complicated than that. Some people are more likely to stay in the same state from month to month than are others. For example, unemployed members of a particular ethnic group may be more likely than members of other groups to remain unemployed once they become unemployed. This is the "mover-stayer" model which has inspired a good deal of work in social mobility studies (see Pullman, 1978 for a review).

Or we might think that the chance of changing state depends on how long one is in that state—the longer one has been unemployed, the more likely, perhaps, that one will remain unemployed. Or the chance of moving from one state to another depends not only on the state one is currently in, but on one's prior history—a history of moving continuously into and out of the labor force might suggest that one is more likely to move out of the labor force next month, even though one is currently working, than someone else who is currently working but has never been out of the labor force since high school graduation. Various combinations might also apply.

Each of these verbal descriptions of the world implies a mathematical model. The availability of longitudinal data makes it possible to test which model presents the most accurate picture of the world as it is and as policies would have to cope with it. If data are really continuous, constituting a life history for each individual, then both a choice of the proper statistical model and the estimation of its parameters are more easily accomplished than if the data are fragmentary, available only at some points in time (Singer and Spilerman, 1976). It is always important, prior to data collection, to consider what models will be fitted, because data irrelevant for one model can be crucial for others. For example, do we want to measure current state only? Duration in current state? Number of switches in state during the period between interviews?

Research is needed on design for panel studies to facilitate discrimination between models fitted to the same fragmentary data. Such research should address questions of the optimum spacing between interviews to balance problems of reliability of retrospection versus costs and delays of reinterviewing (Singer and Spilerman, 1976).[17]

An application of a continuous time model has come out of the longitudinal data generated by the Income Maintenance Experiments (Tuma, Hannan, and Groeneveld, 1979). Three models (one time independent, one contrasting the first six months of the experiment to the succeeding 18 months, and one looking at four successive six-month periods) were used to investigate the impact of support levels on attrition (or withdrawal) from the experiment, and on marital dissolution and remarriage. The findings showed no effect of support level on attrition (cheeringly enough), no systematic effect on remarriage, but a systematic effect of support level on marital dissolution. (Marriages of women receiving income supplements were considerably more likely to break up than marriages of control women, with the effect most noticeable during the first six months, but continuing throughout the two-year period.) Further, the model contrasting the first six months with the succeeding 18 closely predicted the percent of the sample single at each time over the two-year period, suggesting that the two-period model embodied a process of marital dissolution that is compatible with the data.[18]

ORGANIZING DATA LONGITUDINALLY

The organization of data collected longitudinally presents many challenges; as researchers meet them we shall see both methodological progress and rich substantive results. Many data sets that are collected longitudinally are stored in computer files as if they were merely cross-sectional, so that many of the special benefits of longitudinal data cannot be realized. Moreover, the analytic richness of longitudinal data is unavailable without cross referencing between levels of aggregation. Each of these challenges is discussed in turn.

The first challenge of organizing data from longitudinal surveys arises because different numbers of events happen to different people. One person may be hired and fired many times over the years, generating data on the job description and dates of employment for each job. These data must be stored and catalogued as pertaining to this particular person. Another person may stay in the same job throughout the course of the longitudinal study, generating far less data. It becomes a methodological challenge to arrange a computer file that includes all the data for all respondents.

The simple solution allots each respondent the space necessary to record the data for the respondent with the most job changes. This creates an easily used "rectangular" file but uses a great deal of computer space suboptimally and increases the time necessary to access any piece of data. Another strategy is to use a hierarchical, non-rectangular file structure. This economizes on computer space and access time but creates the need for new computational and statistical methods. Such issues of file organization and their consequences constitute an active research area (see, e.g., Ramsøy, 1977); nevertheless data files are already beginning to become available in longitudinal form.[19]

Another challenge for file organization for longitudinal data arises from the need to link various levels of analysis. Often a survey is conducted so that locations (for example, housing units) are sampled. Within the housing units are households, made up of individuals. Typically a separate computer file is maintained for locations, for households, and perhaps for individuals. We can easily visualize an investigation where we find that an individual has experienced an event (say a robbery) and we would then want to ask several levels of questions. Has that person previously been robbed? Has anyone else in the same household been robbed? Was any member of the household that previously lived at this location robbed? These questions are answerable only if efficient cross-referencing between the several data files has been provided.

RESOURCES OF LONGITUDINAL DATA

Longitudinal data today represent an underutilized resource. We are just beginning to explore the richness of the data sets that have been deliberately collected in a longitudinal manner. But, there are other data sets that are only fortuitiously longitudinal that represent an even less exploited resource. The National Crime Survey (NCS), which asks respondents to report victimization, and the Current Population Survey (CPS) are both, in part, longitudinal data sets (see Fienberg, 1980a; Kalachek, 1979). For reasons of economy in sample selection and control of certain kinds of bias, each of those surveys uses rotating panels. The CPS interviews each family eight times: once a month for four months, and after eight months off the panel, once a month for four months again. The NCS also interviews monthly, with a rotation group being interviewed every six months for three years. Each of these samples is designed to give cross-sectional data. That is, the Bureau of the Census, which runs both of these surveys, is interested in aggregate employment and unemployment figures each month, and in aggregate victimization each month.

With some effort, however, the surveys could be organized in longitudinal form and used to examine changes experienced by individuals. Some attempts in this direction have indeed been carried out. A longitudinal data file for persons and households present in the NCS from July 1, 1972 to December 31, 1975 has been created (Reiss, 1980). This file has been used to investigate repeated victimization using loglinear models (Fienberg, 1980b). (Note that the analysis of any repeated event is inherently longitudinal.) Because repeated victimization frequently involves crimes of similar type, further investigation might examine the vulnerability or "proneness" of groups of households or household locations to certain kinds of crime.

There are both limitations and advantages to using the Current Population Survey as a longitudinal survey (Kalachek, 1979). Its advantage is that it is enormously large—56,000 households are interviewed each month, in such a way that 42,000 are common to successive months, and 28,000 common to the same month across a year. This is in contrast, for example, to the original panels of the National Longitudinal Survey (NLS, also often referred to as the Parnes data), each of which contains 5,000 individuals. The breadth of the CPS would permit analysis by subgroups; this is not feasible from the smaller panels. The CPS, for example, could examine the employment experience for black women from the South in a particular age group, while NLS would have too few people in such a specific category to carry out those analyses.

In other senses, however, the CPS is limited. The length of time any given family is included is only sixteen months. Further, in order to serve its primary purpose, the monthly collection of timely cross-sectional unemployment statistics, the CPS interview schedule must be kept brief in order to reduce nonresponse. Thus, the in-depth data available from special panel studies are not available from the CPS.

Some of this lack of depth of the CPS could be compensated for by supplementary questions that are asked once a year. (Thus each family would give two readings on each of these questions, spaced a year apart.) The supplementary questions encompass such areas as job tenure and job mobility, marital and family characteristics, education and work experience, multiple job holding and union membership, school attendance, and farm labor. CPS data files could also be supplemented by statistical matching, described below. A large number of important policy issues could be better examined if these potentially useful files are made available for analysis in longitudinal form.

OTHER ASPECTS OF LONGITUDINAL STUDIES

Besides the challenges of organization of data files, longitudinal studies present design and analytic problems as well. Evidence of what is called "panel bias" suggests that people answer questions differently the second time (and perhaps subsequent times) they are asked than they do the first. Perhaps some purchase can be gotten on this problem by "throwing away" the first interview with a respondent. The National Crime Survey, for example, uses the first interview for bounding purposes only, not for comparative purposes or as cross-sectional data. Thus the first "real" interview (the second actual interview) is more like subsequent interviews than it is like the first. The severity of panel biases, their effect on measures of change, and the extent to which they continue over time in a panel will be matters for investigation as data become more easily available in longitudinal form.

A second problem is that when a family takes part in a survey over time, different family members may be interviewed on different occasions. In the discussion of using proxy respondents to decrease nonresponse, we noted that some respondents report differently about themselves than about other family members. Do such differences occur in longitudinal studies, and if so, what effect do they have on data analyzed longitudinally in terms of families? In terms of individuals?

Still another set of problems with longitudinal surveys involves attrition from the sample. If the housing unit is the sampling unit, but the family is the unit of analysis, what happens when the family moves? What happens when *part* of the family moves, as when a grown child leaves home, or a marriage breaks up? What happens when a person dies? This problem has received little attention from the Census Bureau because for their cross-sectional purposes the household is treated as the unit of analysis. Other large-scale longitudinal studies have answered these questions in various ways. The Health Insurance Study replaces families that move out of the area and hence become ineligible to participate with those who move into the vacated dwelling. In cases of divorce and remarriage of both spouses, the Health Insurance Study chooses one spouse and follows the new family, dropping the other spouse from the sample. The Panel Study of Income Dynamics follows all members of the families originally interviewed in 1968, annually interviewing the head of every family that includes at least one member of the original families. Thus the sample keeps renewing itself with new generations.

Following *individuals* over a long span of years can be particularly difficult, especially if there is a considerable hiatus between interviews, but the success of recent studies suggests it can be accomplished. The secret seems to be telling the respondents that the study is a continuing one, and asking them to give the names of several relatives or friends who would always know how to reach them (Freedman, Thornton, and Camburn, 1980). This seems a good idea for studies dealing with such wholesome activities as family-building and career planning; problems of confidentiality might well arise if the issues were more sensitive.

What happens when a heretofore cooperative respondent disappears or refuses to answer some or all questions? The very longitudinal nature of the studies helps in the solution of such problems. Certainly imputation for item nonresponse (unanswered questions) can be more easily accomplished in longitudinal studies where there is prior information about respondents. For example, estimating a respondent's income this month is easier if we know last month's income for that respondent. Several investigators have presented models that help deal with attrition from longitudinal surveys. They first model the probability of attrition (or nonresponse or self-selection) based on respondent characteristics that are measured within the context of the survey. For example, a model might suggest that the likelihood of moving, and hence being unavailable for interviewing, increases with the experience of having been the victim of a crime. Then they can attempt to adjust estimates of, for example, current victimization or current unemployment for bias caused by attrition (Heckman, 1976, 1979; Hausman and Wise, 1977; and Griliches, et al., 1977).

This problem of attrition bias is a special case of the more general problem of "censoring." Someone who leaves the panel can, of course, not have data observed thereafter; such further data are said to be censored. But even with an intact panel of willing respondents, there are some pieces of data not available at any given time for some individuals. To illustrate: at whatever time we stop to make an analysis of amount of time spent in first job, there are some people who have never switched jobs; for them we can get no measure of how long the first job lasted except to say that it lasted at least from the beginning of the job until the current time. The problem is how to adjust for the censored observations in estimating the average time spent by members of the population in their first job. There has been a recent surge in development of methods for the analysis of such censored data.[20]

Problems of anonymity and confidentiality are especially severe in longitudinal studies because individuals or families must be identified in some manner so that they can be followed over time. Several means of assuring anonymity in longitudinal surveys have, however, been developed (Boruch and Cecil, 1979): respondents may choose aliases and continue to use them; an agency or broker may act as an intermediary between respondent and investigator, releasing only unidentified data to the investigator; or an insulated "link file" system may be created. In this last case, data in the investigator's files are labeled by arbitrary data-linking numbers, identifications are kept in another file and labeled with another set of arbitrary respondent-identifying numbers, and the only file linking the two sets of arbitrary numbers is held by an incorruptible third party. As successive waves of data arrive, the investigator removes identification and relabels with the respondent-identifying set of arbitrary numbers, and ships the data to the third party who removes the respondent-identifying set of arbitrary numbers and substitutes the data-linking set before returning the data to the investigator—ponderous, but seemingly foolproof, and well-adapted to reducing both unit nonresponse and possibilities of breach of confidentiality in longitudinal surveys. Organizations such as the National Opinion Research Center have used link file systems and find that it is crucial and understandably difficult to convince potential respondents of the inviolability of the linkage system.

SOCIAL EXPERIMENTATION

Taking experiments out of the laboratory and into the field is not new; using them as instruments of policy and simultaneously as sources of information about policy is new. There has been a flowering of experimentation to investigate policy alternatives and a corresponding blooming of the methodology to carry out such experiments beginning in the early 1960s. A standard definition of a social experiment states:

> By experiment is meant that one or more treatments (programs) are administered to some set of persons (or other units) drawn at random from a specified population; and that observations (or *measurements*) are made to learn how (or how much) some relevant aspect of their behavior following treatment differs from like behavior on the part of an untreated or control group also drawn at random from the same population (Riecken and Boruch, 1974: 3, emphasis in the original).

The 'random' in this definition is the hallmark of a true social experiment. If people are assigned to treatments at random (rather than by some other method such as self-selection, first-come-first-served, or those judged to be most in need given preference, etc.), then several advantages accrue. First, standard procedures of statistical inference are appropriate for use. And second, any differences found between groups at the end of the experiment can be probabilistically examined to judge whether they result from the treatments or instead reflect pre-existing differences between the groups that were related to whether or not they got treatments.

Controversy about the necessity and feasibility of doing such randomization has long existed. That randomization is important is clear; when randomized and non-randomized evaluations of programs (like the Salk polio vaccine tests) are run in tandem, often the result of the non-randomized study is less clear and compelling than the result of the randomized study (Boruch, 1975a; see also Gilbert, Light, and Mosteller, 1975).

Thus it is not true that non-randomized testing is cheaper and just as good as randomized experimentation.[21] Nevertheless, while true experimentation is the method of choice for drawing conclusions about public policies and programs (as well as about other issues), and can be carried out more frequently than it currently is, and than is often supposed, inferences must sometimes be made from nonexperimental situations. That need can rise (among other reasons) from the pressures of time, expense, or ethics. When circumstances demand that investigators make do with data gathered from nonexperimental situations, prudence insists that special care be taken in the analysis[22] and in making inferential claims. Causal inferences are shaky at best, and alternative explanations for results are always conceivable.

The definition of social experiments stresses that people are drawn at random (via a probability sample) *from a specified population*—and this is an aspect of social experiments that differentiates them from laboratory experiments as usually performed in the social sciences, where frequent subjects are rats or college sophomores. If the purpose of a social experiment is to find out how poor people will react to an income subsidy, then the subsidy must be offered experimentally to poor people. This means that the sampling techniques developed by survey researchers and statisticians are relevant to social experiments, as are the techniques for reducing or coping with nonresponse. Further, the observations, measurements, responses, or outcomes one wishes to examine are usually not as clear-cut as they are in laboratory experiments, where test scores or behavior counts (often computerized) are fairly straightforward. Social experiments have sought to measure program effects such as earned income, housing demand, utilization of health-care services, and distribution of use of electrical power. These complicated concepts are often measured using survey techniques, so the problems faced and knowledge gained in the study of nonsampling variability in nonexperimental surveys is equally applicable to social experiments.

APPROACHES TO THE SPECIAL FEATURES OF SOCIAL EXPERIMENTS

Both the advantages and the special problems of social experiments stem from their scale: that is, their length and complexity. Besides the basic advantage of precision of causal inference, social experiments generate rich data sets that provide opportunity for detailed analysis and model fitting. When many variables are measured over long time spans, unanticipated results can be explored.[23]

Social experiments take a long time to run. Families do not usually react instantaneously to an income supplement or other major program change. Thus, the income maintenance experiments provided support for three- or five-year periods, with one variation in Denver actually running for 20 years (Ferber and Hirsch, 1979). An experiment monitoring the same people over this long time falls into the category of longitudinal studies, and thus suffers from the problems of these studies (e.g., attrition and censoring of data) as well as other problems related to its large scale.

Attrition can be especially damaging in an experiment if it is related to the treatment given. For example, members of a control group or one receiving only minimal benefits from the experimental program may be more likely to drop out than those receiving high benefits. (The entire control sample in one location of the Health Insurance Study was dropped because of lack of cooperation; see Ferber and Hirsch, 1979). Depending on how this attrition is related to the treatments and characteristics of the participants, it may present problems in gauging the effects of the treatments.

Attrition and nonresponse are not the only reasons for missing data in such studies; some variables are intrinsically unobservable for some participants. For example, time until rearrest among parolees is not measurable for those who are not rearrested during the course of the experiment. Again, threshold models (e.g., Heckman, 1976; 1979) may be useful in adjusting for such missing data in an experimental situation. This sort of adjustment was done in an experiment examining employment and earned wages of ex-convicts. The treatments were varying levels of income supplements (Ray, Berk, and Bielby, 1980). These income supplements were estimated to have a greater positive impact on wages when the data were adjusted to account for those not working.

Social experiments also require a great deal of time to plan and manage. An experiment involving trial work periods for recipients of social security disability insurance is an example. As of the summer of 1979, a team of researchers had spent two years in planning, setting budgets, designing measurement devices, and negotiating legislative authorization. They anticipated another year of "facing the contracting process for outside data collection services and working with Social Security operational components in mounting and monitoring the experiments" (Franklin, 1979). These experiments, the largest social experiments ever undertaken, involving some 30,000 people, have now been authorized.

As a potential buyer examines a horse's teeth to validate the seller's claim of its age, so is a social experiment designed to "look into the horse's mouth" and by implementing the proposed program on a controlled and relatively small scale, estimate the effects of a fully implemented program. There is a set of problems, however, in that the "horse" looked at experimentally may not be precisely the same as the one that would be created if the program were fully implemented. These potential sources of bias are recognized by experimenters working in the field, and efforts are being made to measure and control for them (Ferber and Hirsch, 1979). The first such bias, attrition bias, has already been discussed.

Second, people often behave differently when they are in an experiment, simply because they know that they are participating in one. This is the well-known Hawthorne effect.[24] Several social experiments have addressed this problem by including a control group that is not measured at all until the experiment is either over or well underway; the people in this group thus do not know they are in the experiment and their data at the end of the experiment provide a baseline for the measurement of possible Hawthorne effects. Thus in the Health Insurance Study, some members of the control group did not receive an initial physical examination until six months into the experiment.

Next, community effects arise if people's behaviors are conditioned by social norms that would not apply if the program were implemented fully rather than experimentally. For example, a "work ethic" might operate to keep people in the labor force during an income maintenance *experiment,* but might cease to operate if income supplementation were instituted community-wide. Some progress in measuring community effects may come out of the housing allowance experiments. Here one component, designed to measure the impact of housing allowances on supply of housing, offers the program to all eligible families in a housing market rather than a random sample of such families as is done in another component of the experiment, designed to measure demand. Differences in behavior of families in the two component experiments may give an estimate of community effects.

Finally, when families know that the experimental program will last only for a specified period of time, time horizon effects may influence them to behave differently than they would if they knew that a program were permanently in place. Attempts to measure these effects involve varying the length of time that the experimental program will run as one component of the treatments to which participants are randomly assigned. The income maintenance experiments varied in time from three to five years, and even assigned some participants to a 20-year treatment. Clearly, policy makers will not wait 20 years for the results of the experiment, but the behavior of the 20-year group during the early years of the experiment ought to give some clues to the behavior of those for whom time-horizon effects do not operate because they expect the program to be "permanent." Both these time horizon effects and the initial "start-up" effects (people reacting rapidly, for example, to the treatment of a health insurance experiment by undertaking medical care that had been long neglected) lend themselves to analysis by the statistical models discussed in connection with the virtues of longitudinal data.

Large-scale social experiment presents management problems to investigators. Not only are data collection procedures complicated by the enormous number of variables to be measured and kept track of during the long time period of the study, but the actual delivery of the treatments is a very complicated matter, often involving the experimental constitution of a complete social welfare agency. Thus problems of experimentation come to include the coordination between the organization delivering the treatments and the organization measuring their effects.[25]

From these complicated management problems of social experiments arise the twin problems of assessing treatment strength and treatment integrity. In fact, whenever an experiment is conducted there is a question of treatment integrity—whether the experimental treatments that are formally prescribed for subjects are actually given to or experienced by them. There is ample evidence from the literature of social psychological experiments that they often are not. Experimenter effects indicate that experimenters tend to get the results they expect, while in the same experiment, workers with contrary expectations, putatively using the same techniques, get contrary results (see, e.g., Rosenthal, 1966). Evidence on demand characteristics shows that subjects, trying to be cooperative, take cues from the experimental situation to develop hypotheses about what the experiment is trying to prove and then behave in a way they think will help prove these hypotheses (see, e.g., Orne, 1962). Subjects in the social role of the experimental subject tend to behave in a way that will, in some sense, "make a good impression" (see, e.g., Alexander and Knight, 1971).

These problems are exacerbated in large-scale social experiments, simply because their scale is so much larger. The treatments are more complicated to explain, both to those administering them and to those receiving them—and indeed may change operationally over time (actual cash transfers change from month to month in the income maintenance experiments depending on earnings and "tax rate"; payments in the health insurance study change with whether the "deductible" has been fulfilled). Responses are also likely to change according to the participants' understanding of the treatment rather than the experimenter's intentions. For example, using respondents' understandings of the treatments in the Negative Income Tax Experiment produced estimates of the program's effect that were different from estimates based on what the "actual" treatments were supposed to be (Nicholsen and Wright, 1977).

On a less psychological plane, the issues of treatment strength and integrity are intertwined. Strength of treatment addresses whether an intervention is powerful enough to be expected to have some effect if it is applied as prescribed. Treatment integrity addresses whether the treatment applied approaches its prescribed strength, basically asking "What really happened?" Both issues should be faced in the design and analysis of social experiments, though both are difficult and neither is currently investigated routinely (Sechrest and Redner, 1978). One literature review found that of 236 evaluation studies examined, 22% did not measure at all whether the program had been implemented according to stated guides (Bernstein and Freeman, 1975).

Both issues have been addressed in the area of criminal rehabilitation. For example, the question of how much work release might be effective subsumes such questions as "When should work release begin?"; "How long should it last?"; "How good a job at what pay level is required?"; "Will it be effective if it is in a community other than the one to which the prisoner is likely to return?" Similar "How much?" questions can be asked about other rehabilitation efforts such as job training and group counseling (Sechrest and Redner, 1978). While there are no easy answers to these questions, the very act of asking them brings common sense and theoretical as well as empirical knowledge to bear on their possible solutions (Sechrest, et al., 1979).

The question of treatment integrity—how much treatment was actually delivered—has been referred to as the third face of evaluation (the first two being experimental design and measurement of outcome; Quay, 1977). In a setting of group counseling in a prison, questions about what was done might ask how often the groups really met, how good were attendance and participation, how meaningful was the discussion, how well were the leaders trained and motivated, and how much stability the groups maintained. When such questions were asked in one study (Quay, 1977) the answer to each was "Not very." Progress then, in methods for conducting experiments as well as in substantive knowledge, is likely to be achieved by the routinized scrutiny of experiments beforehand for expected treatment strength and afterwards for treatment integrity.

OPTIMUM DESIGN

Social experiments are expensive in time, effort, and money. Including both transfer payments and costs of research, the income maintenance experiments had cost about $70 million by 1975, the Health Insurance Study was projected to cost approximately $50 million, and the housing allowance experiments about $200 million (Ferber and Hirsch, 1979). For this reason it becomes crucially important to design them in such a way that the most knowledge possible is gained from a given expenditure. Methods of optimal experimental design[26] are engineered to do just that. Let us look at the income maintenance experiments as an example. Sets of participating families were given different treatments in the experiments. These treatments were varying support level of payments, defined as percent of the poverty level, and varying "tax rates," or the percent of earnings that was counted (taxed) against support payments. The response measured was earnings during the experiment, expressed as a proportion of normal pre-experimental earnings. Also used as part of the basis for assignment to treatments was the pre-experimental income level expressed as a percent of the poverty level (Conlisk and Watts, 1969).

Traditional experimental design (see, e.g., Cochran, 1978) would have chosen a set of support levels and tax rates, with that choice perhaps based on considerations of what differences between combinations would be of greatest policy importance. Traditional experimental design would have randomly divided the families in a pre-experimental income stratum among the treatment groups, and then done the same with each additional stratum of families. The experimenter might well decide that certain treatment combinations would receive no families from certain strata or that certain treatment combinations would receive a disproportionately large number of families. Such decisions would be based on deliberate judgments about which higher order combinations of treatments and strata would be negligible in their effects on earned income and which would be especially important.

This is a very general and flexible design that makes no assumptions at all about the form of the relationship between the response and the treatments, nor, in its simplest form, about whether families that differ in pre-experimental income will differ in their response to the treatments. It also does not take into account that some treatments (with higher support payments and lower tax rates) are more expensive than others, especially when given to families with low pre-experimental incomes.[27]

If one is willing to make some assumptions about the form of the relationship between treatments and response, statisticians studying response surface methodology[28] have shown that one can choose treatment combinations that are "optimal"—they will, in some sense, maximize the information available from the experiment for a given budget. Alternatively, if the functional form is assumed and the logically possible treatment combinations specified, optimal allocation of families to treatments can be worked out (Aigner, 1979). This latter route was taken by Conlisk and Watts (1969) in designing the New Jersey Negative Income Tax Experiment, using an allocation model that took into account both the cost of the treatment and its policy importance.

One problem with such optimal designs is that they are usually optimal for the form of the relationship specified; if that specification is wrong, then the design can be less good than one that makes fewer assumptions. This problem can be grasped more easily in the context of a simple experiment involving only support payments as the treatment and earned income as the response. If the relationship between support and earned income were believed to be linear, then some fraction (one half, other things being equal) of the available families would be randomly assigned to the lowest support level contemplated and the remainder to the highest. This procedure would be the most efficient for estimating the slope and intercept that fully describe the assumed linear relationship between support and income. If, however, the relationship between support and income is actually curvilinear (for example, if earned income decreases very slowly for low support levels but then drops off rapidly at higher levels), this design would be completely unable to describe the form of the curve. A design that assigned an intermediate support level to some families would be necessary to describe the curvilinear relationship.

This sort of problem may indeed have arisen in the New Jersey Negative Income Tax Experiment because few very poor people were assigned to the expensive treatments (because expensive treatments would have been even more expensive if applied to low-income people). Thus it was difficult to test the truth of the assumption that the effect of the treatments on labor force participation did not vary with pre-experimental income level (see Archibald and Newhouse, 1980). A further problem is that any large experiment has many questions and goals. Optimality for one goal may be less than optimal for another.

Another approach, a "finite selection model," starts out with the number of families to be allocated to each treatment already decided, and assigns, from the pool of available families, the most appropriate families for each treatment. Randomization can be easily introduced, and the computational costs of the assignment process reduced considerably without seriously compromising optimality, by making each choice as the optimum from a randomly chosen subset of the available families. Some problems introduced by the possibly unbalanced designs arising from the Conlisk-Watts procedure are avoided in the finite selection model. The model was developed for the Health Insurance Study and used there and elsewhere (Morris, 1975).

Halfway between the broad general purpose traditional designs that assume little or nothing about the response functions and the highly specified optimal designs is the concept of EVOP (evolutionary operations) (Box, 1978; Madansky, 1980). A small set of treatments is chosen and enough observations are taken to suggest both whether a simple model will fit the data and what changes ought to be made in the treatments in order to maximize (or minimize) the response. (In the New Jersey Negative Income Tax Experiment, clearly, the aim would have been to find the treatments that maximized earned income.) Then another small experiment would be run, either taking more observations in the original treatment region in order to fit a more complicated model, or changing the treatments in order to move toward the maximum response.

Any serious attempt to apply evolutionary operations to social experiments would certainly further increase the already long time necessary to obtain definitive results. Each of the small experiments would have to run for some time before its outcome could be determined for use in planning the next small experiment. But such an approach would be very useful in estimating the real responses to possible variations in policies, in the long run, while offering some interim results that could be useful in more immediate policy planning.

A similarly sequential approach has been used to explore educational alternatives for under-achieving Hawaiian native children. Compared to EVOP as applied to large-scale social experiments, this project is much smaller in scale, uses less formal and complicated statistical technology, and admits more intuitive elements into its evidential base. But the basic idea of letting data from one phase of the investigation formally shape the succeeding phase is similar, and the project has developed an educational program that appears to work (Tharp and Gallimore, 1979). Perhaps the next few years will see an attempt to apply real EVOP methodology to large-scale social experiments.

USES OF ADMINISTRATIVE RECORDS

As information demands become greater, it is natural to look for sources of data that involve less burden on respondents and lower collection costs than those incurred by surveys or experiments. The large sets of administrative records maintained by federal agencies (Social Security Administration, SSA, Internal Revenue Service, IRS, etc.) seem to offer enormous potential for statistical uses.[29]

LINKAGE

Advantages could be realized by using individual administrative data sets themselves. More might well be available if data on individuals or businesses held by different administrative agencies or obtained by surveys could be linked into a file containing considerably more detail than that maintained by any single agency or available from any survey. The 1973 Current Population Survey-Administrative Record Exact Match Study did exactly that, creating an extremely rich data file. Survey records for people in the March 1973 CPS were linked to their earnings and benefit information in Social Security Administration records, and to data from their 1972 income tax returns. The file contains the usual CPS demographic and labor force items, plus the March supplement questions on income and work experience, longitudinal data on earnings from the individual's Summary Earnings Record at Social Security, data on tax units' taxable income from the Internal Revenue Service, and beneficiary status from the Social Security Administration.

Major methodological difficulties had to be solved in implementing this procedure because the various files are maintained for different units. SSA uses the individual covered worker; CPS uses the household, with information solicited for each individual; and the IRS uses the taxpayer, who may be an individual, a couple, or a family. These files are available for public use, and many substantive and methodological studies have used them. (See *Studies from Interagency Data Linkages*, 1980). Early papers during 1975-78 dealt with methodological issues and cross-sectional analyses of income data. More recent studies are using the files to carry on mortality and disability research (see DelBene and Scheuren, 1979). Little attention has been paid to date to the longitudinal aspects of the files, however.

Two linkage projects on a much larger scale are now in the planning stage. The first, the Linked Administrative Sample (LASS) project starts with the Continuous Work History Sample (CWHS) that has been maintained by the Social Security Administration for over forty years. CWHS is a one percent sample of social security accounts, updated each year so that the file is a longitudinal one. (The CWHS has been available to outside researchers; the Tax Reform Act of 1976 has foreclosed the release of information more recent than that date to the public, but the file continues to be updated.) Over the years the file has been used for internal research at the Social Security Administration to keep track of the characteristics of workers covered by Social Security and how this population has changed with legislative changes, and it has been used outside of SSA for research on workforce characteristics, life-cycle earnings, and industrial and environmental health issues. The purpose of the LASS is to supplement the CWHS longitudinal data on earnings and benefit histories with mortality information from the National Center for Health Statistics and individual income tax items obtained from the IRS Statistics of Income Program. The long-term goals of this effort are to develop a source of socioeconomic and job-related mortality and morbidity data which might eventually make possible the separation of residence and occupation influences on health; to construct baseline data on income for small areas to measure the impact of changes in tax policy; and to study regional labor market conditions.

The Survey of Income and Program Participation (SIPP), a longitudinal survey now in its experimental stages, uses administrative records as frames for sampling recipients of programs of income supplementation such as Aid to Families with Dependent Children or Supplementary Social Security benefits. These administrative records will also be matched to the survey results to enrich the data and used as a control to study the accuracy of reporting of income by those surveyed, thus adding to knowledge of response errors. The eventual aim of SIPP is to support policy analysis of a wide range of Federal and State transfer and service programs. Public use data tapes are envisaged (see Griffith and Kasprzyk, 1980).

OTHER ASPECTS OF THE USE OF ADMINISTRATIVE DATA

There are several problems in the use of administrative data for statistical purposes. One is that data collected by an administrative agency as a by-product of its necessary data collection activities are probably less accurate than the primary data. Agency priorities usually involve carefully refining and monitoring the data that are necessary for programs of that agency, while fewer resources are invested in caring for pieces of information that are less important for the agency itself. Thus, for example, some 11% of the workers in the one percent CWHS were found to be miscoded on location of work (Cartwight, 1978). For purposes of recordkeeping in SSA, what matters is the employer for whom the employee works, not the location of the work. This presents no problem when an employer has only one place of business, but problems arise with a multi-establishment employer and a system of optional reporting of place of employment. Problems of a similar type will exist whenever files from different agencies are linked as long as definitions of variables are not the same across agencies; advances will occur when definitions are standardized.

Legal and ethical problems also exist in the use of administrative records for statistical purposes. There are legal restraints and confidentiality rulings that differ across agencies. With certain exceptions, the 1976 Tax Reform Act makes it illegal for the IRS to release data except for purposes of tax administration. Other agencies are governed by comparable legislative requirements for confidentiality; in the development of the Linked Administrative Statistical Sample (LASS), inconsistent regulations are reconciled by attending to the more stringent of the two.

The principle of "functional separation" of data for statistical and administrative uses has been proposed to deal with confidentiality problems (Alexander, 1979). Under such a principle, data that are to be used for statistical purposes may flow from administrative agencies; there is to be no reverse flow. It is also useful to recognize the difference between natural persons and other legal entities in their needs for confidentiality (Federal Committee on Statistical Methodology, Subcommittee on Statistical Uses of Administrative Data, 1980). A continuing problem is that files created for statistical purposes offer the nightmarish possibility of corruption; solutions may lie with the insulated "link-file" system discussed earlier under longitudinal surveys.

One other objection to the use of administrative records for some statistical purposes is that when they are used for program evaluation they may be distorted in order to present a more favorable view of the program (Campbell, 1979). Thus, for example, when the success of a job placement program is evaluated by the number of placements made, there is a tendency to concentrate efforts on the clients easiest to place. Similarly, when the performance of a police department is measured by percentage of cases cleared, crimes may not be recorded when they are reported but only when and if they are cleared.

An exciting development related to the use of administrative records grows out of the literature on imputation for missing data. The linkages between data sets discussed above operate, through the use of such identifiers as social security numbers, to link data related to the same individual or family from the files of two separate administrative agencies. This is called "exact matching." There is also a concept of "statistical matching" (Radner, 1978), where a single data set is created from two sets that do not refer to the same people, in order to create a more comprehensive or accurate set of variables. This is usually done between a household sample survey and an administrative (e.g., tax return) sample, or between two surveys. Matching variables are chosen, in the same sorts of ways as adjustment classes are constructed for imputing missing values, and the closest match, in some sense, for each member of one file is chosen from the members of the other file. The files are then merged and the matched data can be treated as if they were measured for individuals for some analytic purposes.

The worth of such a synthetic data file rests on the similarity of definition and error structure of the matching variables across the original files. Statistical matching is a potentially rich and useful source of detailed data, but the accuracy of estimates made from such files remains to be explored. One proposed method for this exploration, reminiscent of methods proposed to evaluate imputation methods, starts with making estimates from a complete data file which is then artificially broken apart. Various methods of statistical matching could be applied to the fragmented file and the estimates derived from the statistically matched files compared with each other and with those derived from the original complete file (see Federal Committee on Statistical Methodology, Subcommittee on Matching Techniques, 1980).

AND THE FUTURE?

Having examined some of the recent advances in methods for large-scale surveys and experiments, we are perhaps in a position to see what gave rise to such innovations and thus to anticipate what will stimulate the innovations of the next several years if not what such innovations will be.

The availability of data has a tendency to generate the new techniques suitable for their analysis. We have seen how publicly available longitudinal data files have already stimulated the application of mathematical models to increase our understanding of processes. As more longitudinal data are accumulated, new statistical and computational methods will be developed for their organization. As they are organized longitudinally and made available to researchers, we can expect to see further advances in models and methods for their analysis.

Similarly we now have large archives of survey data collected using multistage stratified cluster sampling techniques, but most of our methods for analyzing these data must squeeze them into a mold designed for less complicated stratified samples. There is a need to develop analytic methods tailored to these complicated sampling designs, and a parallel need to experiment with sampling designs that lend themselves to analysis using available multivariate methods.

Available data coupled with policy relevant results from their analysis seem to constitute a particularly potent force in stimulating creative reanalysis, scientific controversy, and methodological progress. Reanalyses of the evaluation of Head Start programs inspired criticism of some widely used techniques of statistical adjustment and gave impetus to the development of new quasi-experimental designs for the accomplishment and analysis of such evaluations (Boruch, 1980; Cook and Campbell, 1979). As results of some of the current large-scale studies accumulate, they will inevitably create controversy and innovation.

We have seen that methodological techniques have a transferability. Experimental design was developed in agriculture, adapted to laboratory experiments in the natural and behavioral sciences, and adapted again to the field situations that are social experiments. But at each adaptation new problems were faced; their solutions constitute some of the methodological advances chronicled above. If we can see new fields for experimentation, we can perhaps anticipate methodological developments. Energy consumption, conservation, and conversion come readily to mind as areas of focus for policy discussion. Although few experiments have been mounted in these areas (the Los Angeles Peak Load Electricity Pricing Experiment is a notable exception), they seem ripe for information seeking to inform policy. Moreover, there is movement toward involving social scientists other than economists in understanding these aspects of energy (*vide* a committee formed by the National Research Council on the behavioral and social aspects of energy consumption). This combination of a relatively unexplored field and some novel points of view may pose new problems and result in methodological innovation.

The very policy relevance of the issues addressed by large-scale surveys and experiments has inspired and should continue to inspire innovation through the communication of results. Complicated methodological techniques may be discussed elliptically between involved professionals, sometimes with little examination of the underlying assumptions and their implications for conclusions. When, however, the results of policy-relevant research must be discussed with policy makers and the general public, and the question "How do you know?" responded to, careful explanation in understandable terms becomes crucial. Such explanation can lead to better understanding of the strengths and weaknesses of techniques, and to their revision. Similarly, attempts to communicate results have been contributing factors to the recent renaissance in statistical graphics (e.g., Fienberg, 1979). This renaissance, in turn, has inspired programs of developing and evaluating the effectiveness of innovative graphic displays (e.g., Kruskal, 1980; Wainer and Francolini, 1980).

The process is a disorderly cumulation; to meet a perceived need for information or to cope with available data we use or adapt methods from the scientific warehouse. This attempt to transfer methods and/or the discovery of their flaws leads to improved methods and the generation of new data. These are then available in the scientific warehouse both to stimulate and to be used in the next cycle of information seeking.

NOTES

1. Thanks are due to a great many people for enormous amounts of assistance during the preparation of this paper. First of all the Review Panel who commented inspiringly through interminable iterations of outlines and drafts: William H. Kruskal, Stephen E. Fienberg, Norman M. Bradburn, and Richard A. Berk. Officers and staff at the Social Science Research Council were also unstinting in time devoted to intellectual guidance and moral support: David L. Sills, Peter B. Read, Kenneth Prewitt, and Roberta Balstad Miller. In trying to describe the cutting edge of research I had to depend in large part on the willingness of investigators to share their work-in-progress and a great many people responded generously, too many to list here but the blanket nature of such thanks should not be read as a detraction from its warmth. Many friends and colleagues with no official connection with the project gave generously of their time to explain and instruct in their areas of special competence and to make comments on various drafts (several of these people might well be considered honorary members of the Review Panel): Eugene Weinstein, Katherine Wallman, Charles Turner, Wendell Thompson, Edward Tufte, Frank Stafford, Charles Smith, Burton Singer, Merrill Shanks, Karl Schuessler, Frederick Scheuren, Gordon Sande, Ingram Olkin, Frederick Mosteller, Susan Miskura, Albert Madansky, Richard Link, Michael Kagay, Edwin Goldfield, Jonathan Cole, Robert Boruch, Albert Biderman, Barbara Bailar. The errors and infelicities, of course, are my very own. Linda D. Anderson performed miracles of typing, both in speed and in beauty.

2. The American Statistical Association has recently published a booklet entitled *What is a Survey?* that clearly explicates the variety, purposes, and methods of basic survey research. (See Ferber et al., 1980.)

3. Useful catalogues of designs for quasi-experiments and the particular threats to validity they defend against have appeared widely in the literature. See, for example, Campbell and Stanley (1963); Campbell (1978); and Cook and Campbell (1979).

4. A glossary of terms used in discussion of nonsampling errors has been prepared, as have several excellent reviews of the literature and bibliographies in recent years (for example, Sudman and Bradburn, 1974; Bailar, 1976; Bradburn, 1978; Dalenius, 1977a, 1977b, 1977c; Kahn and Cannell, 1978; Deighton et al., 1978; Mosteller, 1978), often in connection with continuing programs on research on survey methodology. A special issue of *Sociological Methods and Research* on survey design and analysis concentrating on errors in surveys appeared in November, 1977. Two panels sponsored by the Committee on National Statistics of the National Research Council are at work in the general area.

5. The panel on Survey-based Measures of Subjective Phenomena of the Committee on National Statistics plans a further review of the literature on response sets.

6. Some have argued that the technique is confusing to both interviewers and respondents, and it is certainly true that it reduces the sample size by soliciting answers from only a fraction of the respondents. While the evidence on its efficacy is not conclusive, in 16 studies that compared randomized response with some standard, nine showed a notable reduction in response error (Boruch and Cecil, 1979). An important issue is that when the percent of people engaging in the sensitive behavior is small, the technique seems sensitive to reporting errors in the innocuous question (Shimizu and Bonham, 1978).

7. Sudman and Bradburn (1974) provided a detailed review, as do Kalton and Schuman (1980).

8. The project is being encouraged by the Panel on Survey-based Measures of Subjective Phenomena of the Committee on National Statistics of the National Academy of Sciences/National Research Council.

9. A conference on Computer-Assisted Survey Technology, sponsored by the National Science Foundation and organized by J. Merril Shanks and Howard E. Freeman was held in Berkeley, California in March 1980. *Proceedings* should appear sometime in 1981 with the title *The Emergency of Computer-assisted Survey Research*.

10. See, e.g., Bailar, 1978; Morris, 1979; Brewer and Sarndal, 1979; Little and Rubin, 1979; Kalsbeek, 1980.

11. Deming (1978) presents properties of this estimator and several related ones.

12. Ranking ratio estimators, a somewhat different technique (Deming and Stephan, 1940), adjust for strata much finer than the ones for which outside data are available and so must start by estimating the "outside information" for these strata. This estimation uses methods of iterative scaling also used in other sorts of analyses of cross-classified data (e.g., Bishop, Fienberg, and Holland, 1975). The estimated outside information is then used as part of a ratio adjustment for that stratum. Oh and Scheren (1978) have offered a multivariate version of the raked ratio estimator.

13. These are published in Aziz and Scheuren (1978), as well as in the *Proceedings* volumes for that meeting.

14. A preliminary version of the proceedings has appeared (Panel on Incomplete Data, 1979). The final proceedings volume and the remainder of the reports of the Panel are scheduled to go to press in 1981.

15. Other approaches to the modelling of measurement error than that implied by the concept of total survey error are of course possible and have been suggested. For example, an approach using a set of structural equations to model the relations between a group of questions that all pertain to the same underlying concept, each measuring it imperfectly but together capturing most of its richness, is now widely used. (See Jöreskog and Sörbom, 1979; for a clear exposition of this approach and an enlightening application, see Kohn and Schooler, 1978.)

16 This is the work of the Subcommittee on Nonsampling Errors of the Federal Committee on Statistical Methodology.

17. The research on the relationship between forgetting and telescoping (Sudman and Bradburn, 1973) is relevant here, and there also ought to be consideration of the virtues of irregularly spaced interviews.

18. Another, less substantive but beautifully explicated application of a continuous time model appears in Singer and Spilerman (1977).

19. For example, the National Longitudinal Surveys of Labor Force Experience sponsored by the Labor Department (Bielby, Hawley, and Bills, 1977), the Annual Housing Survey sponsored by HUD (Beveridge and Taylor, 1980), the Panel Study of Income Dynamics (Morgan, 1977), and some parts of the National Crime Survey sponsored by the Law Enforcement Assistance Agency (Reiss, 1980) are now usable longitudinally.

20. A basic reference is Cox, 1972; a recent brief review of the literature is Moses, 1978; and detailed technical expositions are given by Kalbfleisch and Prentice, 1980; and Elandt-Johnson and Johnson, 1980.

21. This and other contentions about the infeasibility of random experiments are listed and refuted by Boruch (1975a).

22. Analytic techniques have been explicated recently by Reichardt (1979) and Anderson et al. (1980).

23. Recall the serendipitous finding that income maintenance increased the rate of marital dissolution of the supported groups.

24. Recent reexamination of the data from the Hawthorne experiments suggests explanations other than the eponymous effect account for the startling rise in productivity of the workers in the experimental room with every change in working conditions, even deleterious ones. Even if the Hawthorne effect did not occur at the Hawthorne factory, however, it has certainly occurred elsewhere.

25. Several sets of practical advice have appeared (e.g., Riecken and Boruch, 1974; Archibald and Newhouse, 1980).

26. See Aigner, 1979, for an excellent discussion.

27. The flexibility of more complicated traditional experimental design is well illustrated in a redesign proposed for the Kansas City Preventive Patrol Experiment. Here design provisions would allow evaluation of treatment integrity which might be jeopardized when patrol cars from beats where manpower was experimentally increased crossed to beats where manpower remained the same. See Fienberg, Larntz, and Reiss, 1976.

28. Bibliographies are supplied by Hill and Hunter (1966); and Herzberg and Cox (1969).

29. In 1977 the Federal Committee on Statistical Methodology formed a subcommittee on Statistical Uses of Administrative Records. The report of that subcommittee, now in draft form, looks at achievements, prospects, and problems in the use of administrative data for statistical purposes. (See Federal Committee on Statistical Methodology, Subcommittee on Statistical Uses . . ., 1980).

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4 The Life-Span Perspective in Social Science Research[1]

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SUMMARY

Behavioral scientists in several disciplines have adopted a new perspective on human development, a perspective which emphasizes that developmental changes in behavior and personality occur throughout the life-span and can assume a new configuration for each group of age mates. The life-span approach asserts that development is as possible among adults and the aged as among infants, even though the nature of development and the rates of change may differ at different ages.

Current research in social stratification, social mobility, psychometric intelligence, and family history is used to illustrate the usefulness of the life-span perspective for investigations of human development. Sociologists and economists are studying how inequalities and differences in wealth, social standing, intellectual performance, and cultural tastes are transmitted from one generation to another. Psychologists are reexamining basic assumptions about the predictability of cognitive and intellectual stability throughout adulthood and about the decline in ability during old age. Individual variation in patterns of intellectual development and potential for change is much greater than previously realized. Historical studies in family history are discovering new continuities and discontinuities. Such research is focusing on individual psychological development; on the influence of changes in family size, composition, and individual development patterns on the character and quality of family life; and on the ability of children to affect their parents' development.

The life-span approach is altering the framework within which a number of issues of public concern are cast and discussed. The approach argues that each successive age group may require different attention at the policy level (e.g., the current elderly population is better educated, healthier and longer-lived, and perhaps more economically sound than previous ones). One of the implications of this research is that we may be moving toward an age-irrelevant society, and that policy makers may begin to make decisions about social needs and social programs (e.g., social security) on the basis of the individuals' needs, functional capacities, etc., rather than their age. The possibility of change throughout life has dramatic implications for education. Not only will continuing adult educational programs become more valuable, but an early investment in an education for a lifetime career may no longer be advisable. More broadly, programs for each age group should be designed to maximize potential at that age (e.g., childhood programs should not be designed with a view toward the child simply as an investment for adulthood).

Life-span research is challenging old ways of thinking about the course of human development, and a new behavioral science of life-course processes—a new discipline—may emerge over the next decade as a result of this interdisciplinary social science research. At a minimum, the prospect over the next five years is for closer collaboration among the several existing disciplines (especially psychology, sociology, history, economics, anthropology, biology) aimed at defining the limits and the potential for change in the human condition.

INTRODUCTION TO THE LIFE-SPAN ORIENTATION

Over the last decade, a convergence of orientation on human development has emerged within several social and behavioral sciences. Known as the "life-span perspective" on development and behavior, this approach reflects many themes and propositions. Its essence, however, is that developmental changes in human behavior occur from conception to death, and arise from a matrix of biological, psychological, social, historical, and evolutionary influences and from their timing across the lives of individuals. Scholarly and popular interest in the themes of this perspective have been intense since 1970. The popular press, for example, has absorbed the ideas of the "mid-life crisis" and life cycle "passages"; there are often articles about the implications of changes in life style such as dual careers, the "empty-nest phase" of marital relationships, greater exposure to chronic disease with increases in longevity, and the return of adults and senior citizens to college and university classrooms. Within the academic community there has been specialization of study: e.g., the growth of life-span developmental psychology; the publication of monograph series on life-span processes; and the organization of interdisciplinary conferences by private and federal agencies that have explored both aging and development as life-long processes.

BASIC THEMES AND PROPOSITIONS

The multidisciplinary study of life-span development that has emerged is an orientation toward constancy and change in personality and behavior from birth to death. This approach is not yet a coherent theory with explicit hypotheses that can be addressed in empirical research. Instead, the recognized consensus is more of a model, paradigm, or world view; as such, it consists of rather general statements that guide more explicit theoretical thinking, the direction of research, and social policy related to human development.

Nevertheless, the paradigmatic themes that have emerged from the several disciplinary influences have already generated a few propositions. These themes and premises reflect a reinterpretation of old evidence about child and adolescent growth, new findings from longitudinal research among the lives of several birth cohorts now entering late adulthood, and intervention studies among the aged. The thematic statements are challenges to conventional thinking and guides to future research. They can be summarized succinctly as follows:

(1) Developmental change occurs over the entire course of life; it is synonymous with aging in the broadest sense. Aging is not limited to any particular time of life; neither is development.
(2) Developmental changes in the course of aging reflect biological, social, psychological, physical, and historical events.
(3) The multiple determinants of constancy and change in behavior and personality express their influences interactively and cumulatively, defining life event or life history trajectories.
(4) Individuals are agents in their own development. Life histories are transactional products of the dialectics among the multiple determinants of development and the motivated, selectively responding person. Generalizations across persons about constancies in human development especially throughout the last half of life, are few and difficult to formulate.
(5) Each new birth cohort potentially ages through a different trajectory of life events, brought about by the impress of sociohistorical change and by individual reactions to it. Historically constant generalizations about developmental changes in aging are fewer or greater as a function of the pace and direction of sociohistorical changes, be they evolutionary or revolutionary.
(6) Intervention efforts among the aged are effective in changing the course of development, even as they are in the young. Behavior and personality apparently remain more malleable throughout the full course of life than becomes apparent in common contemporary social and subcultural settings. The apparent plasticity of manifest patterns of development—untapped reserve or potential—suggests a rethinking of research paradigms and social policies that are predicated on conventional, essentially static models of aging and of stable and universal stages of development from childhood through old age.

These themes and propositions are developed in the most recent multidisciplinary, edited collections: *Life-Span Development and Behavior*, Vol. I (Baltes, 1978) and Vols. 2 and 3 (Baltes and Brim, 1979; 1980); *Aging From Birth To Death* (Riley, 1979); and *Constancy and Change in Human Development* (Brim and Kagan, 1980). (For a detailed discussion of the empirical bases of these themes, see Featherman, 1981.)

HISTORICAL OVERVIEW

Despite the apparent novelty of this perspective and the intellectual and popular interest it has evoked, the themes and propositions that provide the focus for these developments have a long history within the social and behavioral sciences in the U.S. and abroad. Only in the last ten years, however, have they begun to achieve a scientific base, in some instances through independent "discovery" by two or more academic disciplines. They are part of a repeated consideration of the interrelatedness of change across individuals' life cycles and social or institutional change. What is unique about the past decade is that its scientific activity has been extraordinarily productive in sharpening concepts, in suggesting hypotheses and empirical research, and in promoting long-range programmatic study of the relationship between individual and social change within the boundaries of academic disciplines (e.g., psychology, sociology, history, and anthropology). It has also been a period of sustained discussions across disciplinary boundaries, and of acknowledged convergences in certain points of view, optimal research methodologies, and intervention strategies. Some have even speculated that what is emerging from the current discussions and programs of longitudinal research may provide the basis for a new academic discipline that would amalgamate and synthesize the traditions of its parent disciplines (Riley, 1981:340).

To place these achievements in perspective and provide a means of assessing their implications, this essay begins with a brief historical review. It is organized by academic disciplines to highlight specific contributions. This organization emphasizes the view of science as proceeding normally within disciplinary boundaries under the guidance of unique paradigms or metatheories and methods. The intense effort to transcend disciplinary backgrounds and to explore commonalities in life-span concepts and methods is a distinguishing feature of the last decade (and is not fully portrayed by the disciplinary histories). At the same time the several disciplines enrich these explorations of the life-span approach with their unique perspectives through the dialogues and dialectics they promote.

Psychology

Psychologists have been among the most prominent proponents of a life-span approach to the study of human development in the U.S. One reason is that the fundamental research agenda of psychologists is the study of an individual's behavior over time (i.e., Baltes, Reese, and Lipsitt, 1980). Although other disciplines, e.g., sociology and history, also study change, the unit of analysis is frequently not the individual. This difference is fundamental for the life-span approach, as is apparent in two other reasons for the intellectual centrality of psychology to this area: One is the recognized importance of biological or organic substrata of behavior, e.g., enzymal or neural properties of behavior and behavioral change (e.g., Rodin, 1980). Another is the theme of the active organism as an agent in its own development or as the instigator of change (e.g., Lerner and Busch-Rossnagel, forthcoming). In disciplines such as sociology and history that typically study aggregate units of analysis, (e.g., social classes or historical periods) biological and sociobiological antecedents and consequences of change assume less central significance than in psychology. In addition, the individual is often cast as a relatively passive entity in the course of social or historical change.

Thus, the psychologist's focus on the individual change paradigm provides an intellectual basis for the central role of psychology in initiating and integrating a multidisciplinary life-span approach to topics such as aging and human development. That approach emphasizes the capacity of individuals of all ages to select, ignore, and modify "socializing" influences. It reflects a growing conviction that contemporary adults not only continue to develop but also become less similar to each other as they grow older.

A life-span orientation to the study of human development has a long history in psychology. Reinert (1979) traces these roots to the philosophical writings and autobiographical reflections of Aristotle, Democritus, and Augustine and other classical philosophers. Perhaps the most important figure during what Reinert calls the "preliminary period" was Johann Nikolas Tetens (1736–1807), a German philosopher and experimenter in psychology. Tetens emphasized the importance of identifying general psychological laws of behavior through naturalistic observation. He placed the study of "developmental courses" of lives within the span from conception to death and stressed the importance of environmental conditions (e.g., social, cultural) for development.

During the "formative period" (between the late 18th and late 19th centuries), two Europeans played key roles. Friedrich August Carus (1770–1808) saw the course of human development as a series of stages, each flowing into the next and preparing the individual for what comes later in life. He strived to establish a "general age-oriented science," but one in which age was not assumed to be a causal variable *per se* and in which historical context was an important facet of age-related behaviors. Carus's life-span conception of development was not supplanted as an intellectual guidepost for over a century (Reinert, 1979:220). The other key figure was Adolphe Quetelet (1796–1874), whose methodological contributions were as important as the substantive ones. He pioneered the use of cross-sectional analysis for the study of age-specific individual differences in development and emphasized the necessity of longitudinal designs for the analysis of intra-individual change (and interindividual differences in these changes). Quetelet identified the developmental importance of critical periods in the life span and showed empirically that historical events or periods could be associated with changes in age (developmental) functions.

Despite a rich formative history, the emergence of this orientation, especially in American developmental psychology, has been rather recent. The first widely recognized American textbook that espoused a life-span view, *Life: A Psychological Survey*, by Pressey, Janney, and Kuhlen, was published in 1939. Not until the post-WWII period was the rubric "life-span" commonly used to differentiate an "age-irrelevant" developmental psychology from the study of developmental processes in the age-specific academic specialties such as child development or adolescent psychology that had formed in the early decades of this century. Research and teaching programs at the University of Chicago (i.e., Havighurst, Neugarten) and the University of Bonn (i.e., Thomae) were forerunners. In the 1960s and 1970s, several symposia at the University of West Virginia advanced the conceptual and methodological frontiers of the life-span orientation, and the symposia monographs helped to institutionalize this specialization (Goulet and Baltes, 1970; Baltes and Schaie, 1973; Nesselroade and Reese, 1973; Datan and Ginsberg, 1975; Datan and Reese, 1977).

It is likely that progress in life-span thinking about development was arrested by several related factors. One was the intellectual dominance of child-focused developmental psychology. This specialty area placed the primary causes of life-long behavioral tendencies within the childhood years. Associated with the hegemony of child psychology were conceptions of development that limited the scope of developmental thinking. These conceptions—so-called "biological growth models"—assumed an end state (i.e., maturity) toward which development proceeds, sequential and irreversible developmental changes, and universality of developmental patterns across individuals. Placed against many behaviors and psychological characteristics of children and adolescents undergoing apparently rapid quantitative and qualitative changes (e.g., bodily growth, sexual maturation), these modes of thinking about general development had considerable analytical utility. At the same time, the biological growth model did not fit adult behavioral changes as well as it did children's. Some psychologists argued that adults do not develop in the same sense as children and that the domain of developmental psychology (equating behavioral development with restrictive, biological analogues) should be bounded by the age-related "stabilization" of behavioral changes in early adulthood (e.g., Flavell, 1970).

One of the major influences on the shift in the definition and causal explanation of development that occurred in the 1960s arose from longitudinal studies of children initiated prior to WWII. Studies undertaken by the Institute of Human Development at Berkeley and the Fels Institute in Ohio were beginning to report the developmental trajectories for their subjects who were reaching adulthood in the 1960s and 1970s. The availability of these extensive longitudinal data motivated psychologists to address developmental issues over longer segments of life than had been customary. And the empirical findings about the relative pattern of stability and change, predictability and discontinuity, fueled a controversy over fundamental perspectives and definitions (compare Kagan, 1980; Block, 1971; Thomae, 1979; Sears, 1980). The data did not conform to conventional metatheories that had been relatively unchallenged and productive when applied to developmental issues in childhood and adolescence and strong differences in interpretation arose.

An even stronger impetus to the "rediscovery" of life-span orientations may have come from gerontologists. Gerontology as a field of inquiry was itself evolving during the 1950s and 1960s when contributors such as Robert Havighurst, Bernice Neugarten, and James Birren began to articulate a psychology of aging. Gerontology, like other age-specific developmental specializations, was influenced by the dominance of the biological growth model, although here the main focus was on senescence and decline rather than growth and differentiation. However, the orientation of the psychological gerontologists was by necessity much broader than that of their counterparts who studied children. The gerontologists placed biological aging and behavioral changes in older adults within the context of cumulative life histories, linking contemporaneous changes with sequences and events over the entire life span. They became as concerned with the emergence of novel behaviors in their older subjects as they were with ones that could be construed as outgrowths of predisposing earlier experiences. They observed large differences in the courses of aging and in behaviors among adults, and they sought explanation of this variation in historical circumstances and in chance occurrences such as illnesses, accidents, and births of grandchildren that are more individualized in their impact. In short, the psychology of aging encouraged a more contextualistic, historical approach to behavioral change and development, a tendency encouraged by the interdisciplinary character of gerontology as a field of inquiry. (An excellent example of such a contextualistic approach to development is Urie Bronfenbrenner's monograph, *The Ecology Of Human Development*, 1979).

As psychologists enlarged the concept of development to incorporate behavioral changes that were not adequately described by the biological growth model, they turned increasingly to the work of sociologists and historians for whom the context of behavior across the life span was a central focus. The complementarity of the individual change-social change approaches encouraged cross-disciplinary collaboration and the emergence of common perspectives; one illustration is the series, *Life-Span Development and Behavior,* begun in 1978 and edited currently by Paul B. Baltes, a developmental psychologist, and O.G. Brim, Jr., a sociologist. This work is but one of several recent products of the emerging multidisciplinary interest in life-span processes that represents a blending of disciplinary influences, making the identification of unique contributions a difficult task.

Sociology

Unlike psychology, no new life-span specialty has formed within sociology. However, the lack of many visible signs of a new life-span specialization in sociology may simply show that sociologists have not felt the need to "rediscover" this orientation or to differentiate it from their longstanding intellectual concerns with "socialization" (e.g., Brim, 1966; Goslin, 1969) or "age-differentiation" (e.g., Cain, 1959; 1964; Riley et al., 1972; Elder, 1975). Indeed, sociological scholarship on aging from birth to death, amplified by contact with psychologists and historians over the last decade, has only begun to tap the intellectual traditions of a latent life-span approach within the subdisciplines of social psychology, social organization and social demography.

Progress toward a comprehensive integration of these traditions into a sociology of the life course has moved along three loosely coordinated fronts: the sociology of age stratification, socialization, and the social demography of the family. Among the more programmatic contributions toward this integration is the three volume work of Matilda W. Riley and her associates, *Aging and Society* (1968; 1969; 1972). They reviewed the nearly inchoate literature on age-related behaviors of adults in the middle and later years, identified a series of conceptual and methodological flaws, and presented a conceptual model for integrating and promoting multidisciplinary research on aging. The Riley et al. "age stratification" model views persons as aging biologically and psychologically over the entire span of life within an evolving social context.

The age-stratification model emphasizes the social aspects of aging in three respects. First, life-long aging reflects sequences of social positions, or trajectories of social roles and associated statuses and perquisites that have age-related features. For example, schooling in childhood and adolescence typically precedes labor force entrance for American males, followed by marriage or parenthood. Second, social positions carry a burden of custom and rules that prescribe behavior for their occupants. These prescriptions mold and reformulate behavior and personality as the person learns to perform and moves through sequences of positions; also, they regulate the flow or selection of persons into positions. Third, both the patterns of biological aging and the sequences of age-related roles themselves are subject to change, for example, by secular improvements in nutrition or health care, by historical events such as wars and depressions, or by evolving institutional changes like industrialization, retirement legislation, or the diffusion of television. This last aspect implies that each birth cohort potentially ages in a unique way. It also implies that in any given year in which the age differences in a behavior or attitude are measured across a society's population two kinds of differences are manifest: those arising from "normal" aging—i.e., developmental patterns that are relatively invariant across historical time—and those reflecting the impact of unique historical experiences of persons born in different years. Both of these manifestations are abstractions, for what is actually observed is an interaction between cohort experience and age. Finally, it implies that one way in which society's institutions change is through the succession of cohorts—the replacement of older persons by younger ones as carriers of a unique cumulative experience and outlook and with a unique developmental history. Thus, social change and individual (developmental) change are reciprocally and dynamically interrelated.

The conceptual framework developed by Riley and others reflects and summarizes a broad scope of earlier literature on aging and life-course processes. For example, sociologists and social demographers such as Cain (1964), Ryder (1965), and much earlier Karl Mannheim (1928; 1952) elaborated the significance of generational and cohort successions and flows through the society as major mechanisms of social change and of ideological conflict. Sorokin, (1941; 1947), Parsons (1942), and Eisenstadt (1956) focused on the age structure of society and puzzled over the question of why and when age is used by a society as a means of sorting people into positions and as a device for allocating goods and services—much as social class or sex serve these societal purposes. Subsequently, others have elaborated the implications of ordered and disordered flows of birth cohorts for the management of potential conflict by institutions such as the schools and the economy (e.g., Waring, 1975). Some (e.g., Foner and Kertzer, 1978) have attended to other cultural settings, principally the East African "age-set" societies where individuals not only experience life events in an age-related sequence but also belong to a named group of like-aged individuals who make "life-stage" transitions as a group. These cross-societal comparisons have suggested culturally specific as well as universal patterns of aging and human development. This line of inquiry has provided a natural link to an intensifying interest among anthropologists in aging as a life-long process (cf. Keith, 1980).

Finally, the effort by Riley, Neugarten (i.e. Neugarten and Datan, 1973), and other sociologists to articulate the connection between the age-graded features of biological and sociocultural life events, on the one hand, and historical and institutional change, on the other, has linked the life-span approach to other active areas of research on the society's organizing structures. For example, the age stratification model enables sociologists and anthropologists who study macro-social or institutional patterns of socioeconomic inequality and mobility to integrate their research with that of social psychologists and developmentalists studying micro-social change—i.e., change over the course of individuals' lives. (See "The Sociology of Life Chances" below.) These types of integrations have fostered the "multilevel" character of life-span research.

A second sociological tradition that is being tapped in integrating a sociology of the life course is socialization research. "Socialization" is a term used widely since the 1940s to refer to the complex processes whereby an individual learns and modifies the behaviors, values, and emotions that are deemed appropriate by the community and larger society. In the mid-1960s, O.G. Brim, Jr.'s conceptual monograph placed socialization within an explicit life-span orientation (Brim, 1966). It differentiated the socialization patterns of children from those experienced by adults through the life cycle in terms of the demands placed upon the "learner," what was to be learned, and the learner's role in the learning process. Brim thus reflected an orientation that had lain dormant in social psychological writings about "cultural and personality" since the seminal research of W.I. Thomas (Thomas, 1909; Thomas and Znaniecki, 1918) and John Dollard (1935), and tapped even more historical roots into the late 19th century (e.g., Giddings, 1897).

At the same time, John Clausen, a sociologist associated with the longitudinal Berkeley Child Guidance Study, elaborated a concept of life-long behavioral and personality change through a succession of shifts in roles and role sequences that comprised the course of adult life for persons in different social classes (Clausen, 1972). Clausen (1968) also edited a collection of essays on the life-span nature of socialization, an enterprise sponsored by the Social Science Research Council's Committee on Socialization and Social Structure. This work on the development of children into adulthood set the stage for several other empirical studies of adult socialization during the 1970s (e.g., Kohn, 1969; Kohn and Schooler, 1973; 1978). Research on adult socialization was advanced by another SSRC Committee, "Work and Personality in the Middle Years," founded in 1972 under the chairmanship of Orville G. Brim, Jr. This group highlighted the middle years (ages 40–60), an area neglected by the child focus of much developmental research and the focus of gerontology on old age. Likewise the focus on transitions between work and nonwork roles and attention to phenomena such as the "midlife crisis" emphasized the continued development of the individual throughout life and gave conceptual coherence to the study of adult socialization.

By and large, however, socialization research was not cast within a life-span perspective with sustained intensity by sociologists. American sociologists have viewed personality development as part of the agenda of childhood and adolescent socialization—to reflect the template of social norms, cultural values, and sanctioned behaviors of the collectivity as these are impressed upon the preadult. The dominant tendency has been to think of individual behavior in terms of the functioning and persistence of society—socializing the child to assume his or her place in the social order—and therefore to emphasize commonalities in childrearing patterns that reflect themes of continuity (e.g., intergenerational persistence of values) and of consistency (e.g., correspondence between the "needs" or "functions" of society and the personalities or attributes of a society's population). (See Brim and Ryff, 1980; Brim, 1980; Elder, 1975; and DiRenzo, 1977 for insight into these trends within social psychology as a subdiscipline of sociology.) In part, this interrupted and episodic intellectual development is a consequence of sociology's lack of a well articulated concept of personality and of its inattention to mechanisms of personality change (development). In addition, socialization research up to the 1970s focused primarily on role transitions that were substantially correlated with chronological ages—e.g., the "disengagement" or the retired elderly, entry into parenthood—lending it a character not unlike the age-specialized approaches of developmental psychology up to WWII. The intensification of life-span approaches is undoubtedly tied to the contact with life-span developmental psychologists in search of an understanding of "context" as well as to other institutionalizing influences.

The third area in which a life-span orientation is taking form in sociology lies at the interface of social demography and social history. It is a longstanding practice for social demographers, whether sociologists, historians, or economists, to study birth cohorts as a way of gaining insight into the impact of secular change on fertility behaviors, mortality and health, and migration—that is, on behaviors affecting the "demographic equation". The last decade saw the diffusion of the cohort method of analysis and the application of a behavioral approach to the study of change into social or family history (e.g., Vinovskis, 1977). At the same time, sociologists studying the dynamic relation of social structure to personality had begun to probe its historical dimension. For example, Alex Inkeles and David Smith (1974) explored the complexities of contact between "premodern" man with the institutions of industrial society e.g., (factories and schools) to gain an understanding of how the personality traits we associate with modern mankind are elicited and selectively promoted. Glen Elder (1980) contrasted two cohorts of California children who had experienced the economic and social disruptions of the Great Depression at different points in their developmental histories, noting the importance of historical events as major influences on personality differences between groups born at different times but also among persons within a given cohort. These simultaneous intellectual developments came together in a series of cross-disciplinary research projects and monographs (Demos and Boocook, 1978; Hareven, 1978) in which scholars viewed personality and family structure as both a reflection and a modifier of historical change during the nineteenth century. (See the subsequent section "The Social History of Family Relations and Human Development.")

Other Disciplines

A life-span orientation to behavioral change also emerged from the work of historians on family dynamics during industrialization in Europe and North America. Vinovskis (1977) notes that multidisciplinary interest in the historical family altered the traditional methods and conceptual models that historians used. For example, to recreate the structure and processes of family life they began to utilize quantitative data from censuses and vital records. Historical demographers such as Louis Henry (1956) and E. Wrigley (1969) used parish records, while Peter Laslett (1972) at Cambridge University reconstructed preindustrial family typologies from manuscript censuses. The latter scholarship revealed that conventional thinking about the large, extended family of preindustrial times was mistaken. In fact, family size was small, nuclear in form, and rather constant over time and cultures. But this work was later criticized by Lutz Berkner (1975) and others for its static approach to the family—in other words, for its lack of a dynamic, life-course perspective. Research into the historical family also drew from family sociologists and the concept of the "family cycle" (Glick, 1947; Hill and Mattessich, 1980). This work has attempted to understand the changing role of the family in terms of the interplay of the sociopsychological development of its constituents, the developmental tempo of the family or household aggregate, and the penetration of historical events and secular changes. In effect, the new behavioral approach of social historians has come to be a study of the dialectical relationships among individual time, social time, and historical time (e.g., Hareven, 1977; a similar set of distinctions about the various tempos of individuals' lives has been made by non-historians, e.g., Neugarten, and Hagestad, 1976; Klaus Riegel, 1979).

Economists have a somewhat longer history of interest than historians in life-long behavioral changes, although their contributions to an emerging multidisciplinary conception of human development and social change during the last decade have been slight. This lack of influence is rather surprising, since the ideas that individuals are human agents of production and that investments in human capital (e.g., skills and abilities) are components of production are old ones (Marshall, 1948; see Rosen, 1977, for a review of recent empirical research). A systematic statement of human capital theory by Gary Becker (1964) prompted economists to develop theories of "permanent" earnings, and to analyze life-time decisions about work and leisure as well as longitudinal trajectories of earnings. For labor economists, this life-span approach was as revolutionary as were earlier developments in life-time consumption decisions (Rosen, 1977:4; see Stigler (1954) for a review of the history of economic research on consumption). Becker's (1965) seminal writings on the allocation of time to home production as well as to work in the conventional (paid) economy formed the core of the "new home economics," an approach that has led to the reorganization of university-based schools of home economics and increases in their faculties of behavioral scientists trained in economics and child psychology. The empirical work in life cycle economics over the last decade has demonstrated a decidedly demographic character; for example, being applied to the analysis of fertility behaviors in connection with labor force participation (e.g., Easterlin, 1980). Some economic writings on social security also show evidence of a life-span orientation (e.g., Modigliani, 1966; Heckman, 1974). This work casts the economic decisions of the parental generation (e.g., investments in their own retirement security through time at work and savings, and investments of time in developing the human capital of their children) in terms of the expected behaviors of children when the latter are of working age and the former are in the post-productive years.

Perhaps the lesser role of economics in influencing a life-span approach to behavior reflects the field's narrow focus on the optimizing, rational decision-maker and the relatively minor impact of "psychological economics" (Katona, 1975) within the discipline. (One exception to this observation is the 14-year study by James Morgan and associates (e.g., Duncan and Morgan, 1980) of individual and family economic behaviors. These studies are rich in the behavioral and psychological data from which life-span analyses can be executed.) Moreover, the human capital orientation in labor economics takes a view of human development that contrasts with a central tenet of the life-span approach. Namely, these human capital theorists see the potentials for up-grading skills or changing the competitive qualifications of workers in rather determinate age-graded terms. That is, workers (and their potential and actual employers) have a finite range of years (ages) in which to invest in improving or altering their "stocks" of human capital. The range is limited according to the theoretical assumption—now being challenged by life-span research in other disciplines—that capacities and interests to learn and to contribute productively to the economy are greatest in the young and deteriorate after middle-age. If the corpus of emerging life-span research is assimilated by economics over the next decade, one should see some reorientation of both theory and research within the human capital framework. At the same time, the quantitative formalism of this economic approach holds promising benefits for life-span research in other disciplines, as illustrated, for example, by the influence of econometrics on life-span approaches to the study of social mobility and inequality in sociology (see "The Sociology of Life Chances" below).

Anthropological research on culture and personality played a major historical role from the 1920s to the 1940s in sharpening the concept of socialization as used by sociologists and anthropologists (Clausen, 1968). These studies were rooted in the influence of Franz Boas, primarily through his students, Ruth Benedict and Margaret Mead. Benedict's (1938) paper on continuities and discontinuities in cultural conditioning conveyed a life-span theme in characterizing the synchronies and asynchronies between biological changes in individuals over the life cycle and the demands of culturally scheduled shifts in roles, responsibilities, and expected abilities. Edward Sapir (1934) was among the first anthropologists to emphasize the reciprocal relationship between personality and culture—to view personality as a transducer of cultural influences rather than as the passive expression of them. This view contrasted with the major theme of cultural continuity and the emergence of modal personalities within cultural contexts that mirrored the neo-Freudian psychoanalytic influence of Abram Kardiner (1939), even though the latter introduced an explicitly inter-generational linkage into the relationship between personality and the social system.

Culturally defined stages of the life cycle have been used by ethnographers to organize and describe cultures. And a subdiscipline of anthropological gerontology has emerged since WWII in which the roles, statuses, and treatment of old people is the focus in both cross-cultural comparisons (e.g., Simmons, 1945; Cowgill and Holmes, 1972) and domestic studies (e.g., Clark and Anderson, 1967; Myerhoff and Simic, 1978; Keith, 1979). This body of work has served an important "debunking" function, showing how North American conceptions of the behaviors of the elderly may be culturally specific and not an inevitable feature of biological aging. An excellent example is the challenge to Cumming and Henry's (1961) "disengagement" hypothesis. Psychological and social withdrawal by the elderly—the lack of vitality, intellectual activity, and independence—are not universal behaviors, even among all North American ethnic groups (e.g., Kiefer, 1974; Vatuk, 1980; Cool, 1980).

Valuable as this anthropological work has been as a corrective on ethnocentric perspectives and as a sharpening influence on conceptual thinking, until recently it has not manifested an explicit life-span orientation. That is, an "anthropology of age . . . is barely being organized" (Keith, 1980). However, anthropological research on age as a basis of social organization is now underway. For example, culturally defined markers such as puberty, marriage of the first son, or death of a parent are being studied for their use as scheduling signals for transitions from one "stage" of life to the next—(e.g., Stewart, 1977; Foner and Kertzer, 1978). Other work focuses on individual differences in the course of aging and human development *within* a cultural setting (e.g., LeVine, 1978), and on the capacity of older persons to create cultural norms for age-related behaviors through innovative formation of "senior citizens" communities (e.g., Rosow, 1976).

It seems obvious in retrospect that the broad and diffuse historical roots of a life-span approach to behavioral change and development within several of the social sciences might have prompted cross-disciplinary scholarship. Initial realization of this potential within the last decade has been aided by the institutionalizing activities of private foundations, interdisciplinary professional organizations, and federal mission agencies. What has emerged from this synergism of influences both inside and outside the academy is not yet a theory with explicit hypotheses that can be addressed in empirical research. Instead, the recognized consensus is more of a model, paradigm, or world view than an explicit theory. As such, it consists in the main of rather general statements that guide more explicit theoretical thinking and the direction of research and social policy related to human development and social change. It is to be judged more for its usefulness in this latter respect than for its truthfulness as systematic theoretical statements that can be tested scientifically.

The following section illustrates this usefulness in three research arenas—arenas in which the life-span approach has reoriented concepts and methods, led to cumulative science, or prompted productive confrontations over metatheoretical differences. The sociology of life chances, psychometric intelligence, and the social history of family relations and human development each illustrate the application or explication of some basic life-span themes and propositions within research programs of three disciplines.

NEW APPROACHES IN RESEARCH THAT REFLECT A LIFE-SPAN ORIENTATION

It is premature to predict whether a life-span approach to the study of development and aging will ultimately blossom into a new discipline with coherent theory and special methods. One early (but not definitive) indication is whether applications of the thematic orientation produce cumulative social science and prompt the development of paradigm shifts within existing disciplines. Within the last ten years there have been promising signs for the vitality of the life-span perspective applied *within* existing disciplines of sociology, psychology, and social history. For example, the crystallization of a life-span paradigm in the study of social inequality and mobility by sociologists and some economists is quite visible. This scholarly development illustrates the scientific fruitfulness of the life-span approach as a basis for cumulating and integrating social science research—across disciplinary boundaries and levels of analysis (i.e., micro-social/individual v.s. macro-social/institutional levels).

THE SOCIOLOGY OF LIFE CHANCES: SOCIAL INEQUALITY AND STRATIFICATION IN LIFE-SPAN PERSPECTIVE

Over the last two decades, progress toward cumulative social science has been greater in the subdiscipline of social stratification and mobility research than in any other field of sociology. In recognizing this achievement, there can be little dispute about the significance of Blau and Duncan's (1967) monograph, *The American Occupational Structure*, for sociological theory and research during this period. This work and the related writings of Duncan recast the empirical study of social mobility into inquiries about the inter- and intragenerational processes of socioeconomic stratification. They provided a rudimentary life-span framework—the socioeconomic life cycle—for cumulative studies that extended and elaborated the descriptive features of stratification as a dynamic process of generational and cohort replacement in the society over time. This framework helped to organize and focus discussion about questions of inequality and the transmission of differential opportunities from generation to generation, a discussion that involved a variety of theoretical points of departure and social scientists outside the discipline. It provided a focus for discussions of public policy about poverty and human rights that prevailed during the 1960s and early 1970s as well as for debates between academic scholars. More generally, the line of work associated with Duncan and *The American Occupational Structure* became an exemplar for the design and analysis of national studies of mobility and inequality. Yet the greatest impact of this program of research on the discipline may have been through its introduction of an approach to "causal modeling" of hypothesized processual relationships (e.g., social mobility) that could be applied to areas other than social inequality and mobility.

Blau and Duncan cast the study of social mobility as the study of the process of stratification. Following Sorokin (1927), they conceived of mobility as a process of social metabolism whereby the inequalities that characterize the society in one generation are reproduced, in whole or in part, in the next. By studying intergenerational mechanisms of socioeconomic transfer and factors that mitigate the effects of these mechanisms in the lives of individuals, they saw themselves to be investigating societal changes in the dispersion of socioeconomic statuses through the succession of generations. (Note the parallels with the Riley et al., (1972) "age-stratification" model.)

Duncan's (1967) schema of the socioeconomic life cycle expressed this process of stratification in terms of life-span experiences of a hypothetical birth cohort. It characterized inequalities within the cohort at birth by the socioeconomic statuses, genetic endowments, cultural and racial features, and related factors across parental households and community milieus. These inequalities of social background were taken as the antecedents of educational differences, which in turn were antecedent to variability in occupational and economic statuses across the working life of the cohort. By studying interindividual differences in hierarchical standing across the successive "stages" or phases of the cohort life cycle, Blau and Duncan portrayed the pattern of social mobility over the life span. Their framework permitted them to examine, for example, to what extent years of school attainment across individuals reorganized the patterns of socioeconomic inequality ascribed by social background, as the cohort entered the work force and achieved places in the social hierarchy. By comparing and contrasting this process of stratification in the experiences of successive cohorts, they were able to assess changes in inequality in the society that were associated with changes in the antecedent-consequent relationships between social background, schooling, and occupational careers.

Path Analysis and Structural Equation Models

The impact of both this definition of social stratification and the framework of its study might not have been so pervasive or long-lasting without Duncan's (1966b) introduction of path analysis as a statistical tool for sociological research. Indeed, neither the conceptual point of view embodied in the socioeconomic life cycle nor path analysis itself was the discovery of Blau or Duncan. But the conjunction of the two was a powerful combination that both added to the scientific potential of the Duncan-Blau approach to stratification and illustrated how sociologists might represent and study "causal" processes generally.

Path analysis, developed by the population geneticist Sewall Wright, enabled Duncan to partition the statistical correlations among the constituent phases of the socioeconomic life cycle (i.e., the relation between two instances of interindividual differences) into the quantifiable paths of direct and indirect influence between (hypothetically) antecedent and consequent events. For example, the correlation of social background and adult socioeconomic status (e.g., as indexed by parental and adult occupational prestige scores) could be decomposed algebraically into a precise statistical estimate of the direct effect of background on attainment and the indirect effect of background through schooling. In addition, in order to use this statistical method, the analyst was forced to be explicit about the hypothetical model to be estimated: that is, to specify all direct and indirect relationships and to examine variance left unexplained in each variable by the "causal" system of alleged antecedents. So, for example, Blau and Duncan could analyze the mobility-inducing effects of formal schooling that were independent from inequalities of social background—i.e., inequalities of background that were transmitted through schooling and converted into inequalities in the cohort's occupational attainments in adulthood.

The analytical power that path analysis provided for stratification research was twofold. First, its requirement for a precisely specified model and its capacity to provide statistical estimates of the model's credibility helped to formalize and make concrete the theoretical discussions of mobility processes. Analysts could visualize and critique each other's work far more easily than before because of the technique's specificity about the entire system of relationships being considered and/or excluded. This facility increased the frequency of cross-disciplinary citation, especially between economists and sociologists nominally at work on the same topic; it also increased the rigor with which theoretical disagreements could be pursued. Second, path analysis led to rapid accumulation of descriptive findings and to a deeper understanding of the process of stratification. Because the technique was based on product-moment correlations, analysts could synthesize complex path models from fragments of data across several independent inquiries, subject to the constraints of population and sampling comparabilities. This strategy of incremental model building is illustrated by Duncan, Featherman, and Duncan (1972) who elaborated and extended the basic 5-variable model that underlay the analysis of *The American Occupational Structure*. They introduced cognitive and motivational variables that were thought to intervene between social background and scholastic attainment, examined the potential of schools to affect the distribution of achievement apart from the personal and background qualities of students in these schools, and investigated the role of selected life-cycle events in adulthood in altering the pattern of socioeconomic careers.

Two other instances of the integrating effect of path analysis (structural equation methods) and the life-span approach appear in the respective writings of William H. Sewell and Melvin Kohn and their colleagues. Sewell has followed a longitudinal panel of Wisconsin high school seniors for over 20 years. The richness of the data that Sewell and associates have collected on social background, schooling, work histories, and life events from this cohort suits the application of structural equation methods. Their "Wisconsin status attainment model" (e.g., Sewell, Haller, and Portes, 1969; Sewell and Hauser, 1975)—a sociopsychological conception of social stratification—in some sense anticipated the Blau-Duncan framework for the socioeconomic life cycle. But by the mid-1970s a rapidly expanding literature had appeared in which analysts at Wisconsin and elsewhere both elaborated and replicated the quantitative statistical models of social (institutional), psychological (individual) and social psychological (interpersonal) factors in educational, occupational, and economic achievement (see Sewell and Hauser, 1980, for a comprehensive summary).

Melvin Kohn and associates at the National Institute of Mental Health have bridged the traditions of Duncan-Blau-Sewell stratification research and psychological studies of mental health (Kohn, 1969, Kohn and Schooler, 1973; 1978). By following a national sample of adult male workers for roughly a decade, Kohn has studied how the requirements and organization of work and job changes influence the values of workers, the goals they have in rearing their children, and even the men's cognitive or intellectual styles. This work also has adopted the quantitative statistical models of stratification research to explicate a life-span conception of the interplay between work histories and personality. For example, Kohn and colleagues demonstrate the reciprocal relationships between changes in the demands of successive work situations—e.g., whether the jobs demanded self-direction or were highly supervised; whether they called for the handling of complex novel circumstances or were substantially routinized—and changes in the intellectual capacities of workers in different occupational trajectories or job sequences. While it was true that men with greater potential at the outset were recruited more frequently into jobs requiring greater intellectual flexibility, it was just as likely that the man was socialized by the job irrespective of personality or sociological factors at the beginning of the study. By implication, personality change—i.e., cognitive capacities—after childhood and adolescence can be observed readily through the study of successive role contexts that organize the tempo and content of adult behavior.

The influence of *The American Occupational Structure* ranged beyond stratification research to alter the empirical standards of sociological inquiry. In turn, these developments reflected back on stratification research to increase its quantitative and statistical complexity. At the time *The American Occupational Structure* was published, sociologists were developing methodologies for "causal" analysis using survey data. Duncan's introduction of path analysis into sociology, coupled with its visibly productive use in stratification research, met a receptive audience in the discipline. Later, Duncan and others recognized relationships among econometrics, psychometrics, path analysis, and structural equation models, as illustrated in Duncan's (1975) primer, *Introduction to Structural Equation Models*. (See Bielby and Hauser, 1977b, for a review of the increasing use of structural equation models in sociology.) This intellectual bridge, together with the development of statistically efficient computer programs for estimating complex structural equations with latent or unobserved variables (e.g., Jöreskog and Sörbom, 1979), invited the introduction of new technologies in economics and educational psychology into the sociology of stratification and permitted even further precision in model construction and estimation. For example, Bielby (Bielby et al., 1977; Bielby and Hauser, 1977a) has compared interpretations of the role of schooling in occupational and economic attainment in which detailed issues of data quality—errors in variables and relationships—are modeled explicitly as part of the theories to be compared. In one sense this mode of theory specification epitomizes the positivistic approach within sociology, for it takes the measurement of "true" relationships and "valid" concepts as equally important.

In sum, the stimulus of Blau and Duncan's life-span approach to the study of social stratification had wide-ranging responses in sociology. Yet the impact of this work is best understood as representing the interdependence among new ways of dynamic thinking about sociological relationships, a search for new technologies that are appropriate for this new approach, and the availability of research questions that could be answered (or rephrased) better through the application of these techniques. Through this interplay, richly detailed quantitative (statistical) models of the process of stratification have emerged, and the full potential for further elaboration and synthesis is as yet untapped. Nevertheless, progress toward cumulative social science has proceeded apace with marked upgrading in the quantitative sophistication that is required for academic sociologists who seek to keep up with, let alone contribute to, this field.

Issues of Public Policy

Another quite important consequence of this development in sociological research was the greater ease with which it promoted and focused policy-related discussions about inequality, discrimination, and opportunities for mobility. Several factors facilitated this practical outcome of academic research. One was the historical influence of the social indicators "movement" during the late '60s and early '70s. This public policy-related emphasis on societal monitoring and the development of normative statistical indicators of social process recognized and embraced models such as that of the socioeconomic life cycle (e.g., Land and Spilerman, 1975). The connection between the Duncan-Blau approach, with its visibly demographic conceptual base, and efforts of the time to develop a set of demographic social accounts prompted this recognition. Duncan himself authored a chapter, "How Much Opportunity is There?" in the first federal social report (Panel on Social Indicators, 1969) in which data from the Blau-Duncan study appeared.

The second factor was connected directly with policy debates, within academe and without. *The American Occupational Structure* was published just after the Civil Rights Act of 1964, and in the midst of political and social attention to President Johnson's "Great Society" program. Life-span statistical models of the socioeconomic life cycle often helped to focus questions of inequality and mobility.

The best illustration of this stimulus, which brought widespread publicity to the field, was Christopher Jencks' *Inequality* (Jencks, et al., 1972). Jencks used structural equations, the framework of the socioeconomic life cycle, the approach of incremental model building, and longitudinal data about social background, schooling, and work careers to discuss the policy implications of the manifest pattern of inequality and its transmission across generations. More than any other recent piece of social science research and policy analysis, *Inequality* exemplified for the public and the social science community alike the "practical" value of this approach to issues in social stratification.

Life-Span Themes Emerging in Stratification Research

Sociologists who study patterns of inequality and social mobility in American society, as well as those who reflect on their implications for public policy, have begun to recognize that some of the same themes that characterize human development in life-span perspective also apply to the socioeconomic life cycle. In constructing this integration, the Riley et al. model of age stratification (1972; 1976) has supplied a highly useful conceptual schema. If one thinks of the process of stratification as consisting of life-long trajectories of achievement behaviors, then growing evidence from research on the socioeconomic life cycle indicates that the developmental course of achievement 1) is responsive to many causes, 2) proceeds in many directions, 3) is both continuous and discontinuous, 4) entails greater interindividual differences as it unfolds, and 5) varies across the experiences of successive birth cohorts. In addition this complex pattern of achievement throughout the life course is generated by age-graded events, cohort-forming events, as well as "idiosyncratic" events in each individual's life. As such, discontinuities in achievement from one phase of life to the next are to be as expected as continuities. And, patterns of continuity and discontinuity in achievement are historically variable. Selected findings from the cumulation of stratification research amplify these points and illustrate an empirical base of life-span propositions and themes.

Some of the strongest continuities in achievement are intergenerational; for example, correlations between the parental and filial generations in performances on standardized IQ tests. Sociologists conceive of IQ as the measured ability to do school work; an IQ score is, among other things, a performance on an achievement task. Interindividual differences in IQ tend to asymptote between ages 8–10; thereafter, inequality (but not necessarily plasticity) in this form of scholastic achievement remains very constant through adolescence. Whether it does so thereafter is not well established (Schaie, 1979). Neither are the reasons for this developmental pattern well understood; it may reflect measurement error, lagged genetic effects, age-graded school environments, or all of these. The parent-child or intergenerational correlation of IQ is roughly 0.5; but the intergenerational discontinuity in this form of achievement is large. For example, a linear combination of social background characteristics—social class, race, region of residence—accounts for less than half of the variation among children's IQ scores (Featherman, 1980).

Other scholastic achievements (e.g., grades in courses, grade point average, teacher evaluations, years of school completed) and attainments in the world of work (e.g., earnings) are less connected to the similar social achievements of the parental generation than is IQ. The life-cycle pattern is one of greater attenuation of discontinuity as the filial generation ages. In addition, secular trend or social change across the experiences of successive birth cohorts of Americans (and perhaps elsewhere) appears to be weakening these linkages even further. Take for example the length of formal schooling—years completed. The major predictor of length of schooling is not parental social "class" but son's or daughter's IQ (Featherman, 1980). Educational aspirations, significant others' school plans, IQ, and grade point average explain about 70% of educational differences among individuals. Interestingly, the net effects of parental characteristics are effectively zero in these analyses. And, across successive birth cohorts of at least American men, these associations of social background (e.g., race, class, farm origins) are getting weaker (Featherman and Hauser, 1978). At least this is so for education through grade 12. In a major respect, this declining persistence of achievement from generation to generation stems from secular change in the population distribution of schooling—in the lower tail. Perhaps this reflects a legacy of industrialization and child labor laws. In any case, historical change has altered the intergenerational pattern of continuity and change in scholastic achievement.

Turning to occupations and careers, one finds, at least for the U.S., secular declines in the predictability of achievement from the attainments of parents and associated aspects of social background. But unlike the situation for length of schooling, this trend toward greater discontinuity in socioeconomic achievement is not connected to overall reductions in occupational inequality—in the distribution of the "statuses" of jobs on some scale of social standing or income. Rather, it seems to arise from the substitution of formal education for social class or background as the means of access to better jobs or careers. Obversely, the continuity between achievement in school and at work has gained, especially the relative economic value of higher education (Featherman and Hauser, 1978).

Explaining the overall trend toward greater continuity between the scholastic achievements of youths and the occupational and economic attainments of adults is problematic. Whether it reflects greater valuation of higher education in post-industrial society, the effects of "credentialism" in the allocation of workers to slots in the economy, or both is not known from available research (Featherman and Hauser, 1978; Featherman, 1980).

There are some major exceptions to this historical trend. One involves black workers, for whom intergenerational continuities of achievement—modest though they are for Americans overall—are just now beginning to approximate the pattern that has been typical in white families (Featherman and Hauser, 1978). Another exception involves young white males who were under age 35 in the mid-1970s. For these men, the economic value of higher education seemed to have fallen as they took their first jobs. Based on recent analyses, it is possible to interpret such a cohort pattern as a temporary aberration that stemmed from a unique confluence of demographic, economic, and historical events (unprecedented cohort size, downturn in federal expenditures for research and development, and the effects of the Vietnam military draft on school attendance patterns; see Featherman and Hauser, 1978). But the important point for a consideration of life-time continuities in achievement and their vulnerability to historical and social change is that this unique confluence may have cost the college class of 1974 in the U.S. about 10% of its life-time earnings (Welch, 1979).

The normative features of the age-graded life cycle are linked to achievement patterns, too. For any given birth cohort there is a statistically normative age profile to the entrance into and exit from the family of origin, school, work, and the family of procreation (Hogan, 1978). Whether such age-graded behaviors are socially normative—subject to positive/negative sanctioning—in addition to being statistically normative has yet to be firmly established. But there are consequences for achievement that ensue from deviations from the normative order and pace of life-cycle events (e.g., Hogan, 1980). These effects are easiest to illustrate in contrasting the connections between jobs and schooling for American women with those of men. Secular trends in the American female life cycle during the 1970s have markedly changed the labor force participation of women in the prime marital and childbearing ages—25 to 34. Whereas two decades ago only one-third of such women worked, today about 55% do. Seventy-five percent of women in that age bracket who do not have children are employed. However, over 90% of the men in these ages are in the labor force, and they tend to work with fewer interruptions and more frequently in full-time jobs. Thus, despite recent shifts that have rendered the female life cycle more like that of the male, the family cycle is still more integrally related to the socioeconomic life cycle of females than of males (Van Dusen and Sheldon, 1976).

What are the consequences for achievement? Relative to males, working women tend to experience more downward social mobility as they have their families and find their own careers. They acquire less job experience at each age than men, making job-to-job moves less predictable and less conditional on job characteristics than for men. There is less continuity of occupational achievement for women (Dunton and Featherman, forthcoming). In addition, the connection of schooling to successive jobs differs. For men, the direct influence of formal schooling on jobs is greatest at career beginnings (i.e., first job). It declines thereafter as experience and on-the-job training become more important for subsequent career moves. For women, however, formal schooling retains importance as the major access to subsequent jobs as women are forced to renegotiate for new jobs on the basis of their school credentials or formal training rather than on a stream of cumulative experience. Overall, however, the net effect is for less continuity between achievement in school and in work for women as a function of "deviant" age-grade patterns in their socioeconomic life cycle (Sewell et al., 1980).

In this brief summary of cumulative research on the process of stratification one sees the imprint of a life-span orientation. Achievement behaviors across the life cycle take place in a sequence of institutional contexts—the home, school, work/economy. The age-graded features of this sequence give rise to the socioeconomic life cycle as one aspect of the general life course. Social changes in the connections between these institutions alter the pattern of continuity and change in human development, as do factors that independently may affect the sequence and pace of life-cycle transitions. In the case of achievement behaviors, especially for men, the drift of change in social institutions over the last several decades has been to lessen the possibility of continuity in the developmental differences among individuals as they age from childhood through adulthood.

A second arena of research—psychometric intelligence—illustrates how the adoption of the life-span orientation has led to metatheoretical debates, reconceptualization, and the search for new methodologies in developmental psychology. It represents a major intellectual testing ground for the scientific vitality and promise of life-span themes and propositions.

PSYCHOMETRIC INTELLIGENCE: COMPETING INTERPRETATIONS ABOUT DEVELOPMENTAL CHANGE IN ADULTHOOD AND OLD AGE

Sociologists and psychologists have longstanding interests in the cognitive development of children and adolescents, and tests of intelligence have been used to measure growth and change in mental abilities since the early decades of the 20th century. Developmental research on mental abilities has been focused on scholastic achievement, on performance in the formal school systems by predicting which children were less (or more) likely to be able to do school work at each grade level. Among the topics of great interest is whether children are promoted on the basis of tested ability or, alternatively, on the basis of social class and other factors of social background. (Empirically one observes a positive correlation between socioeconomic strata and IQ scores; it arises from both the differential genetic endowments and cultural contexts of social groups [e.g., Scarr and Weinberg, 1978; see Featherman, 1980, for a review of research].) Not until WWII were IQ tests administered widely to adults in the U.S. or were social scientists studying the differential abilities of adults. Even then, psychometric research on the intelligence of young adults predominated, as scientists examined the influences of scholastic success and achievements in the world of work.

Developmental Aspects of Intelligence

Within psychology, theoretical dissensus has surrounded the study of cognitive development in adults and the aged. For instance, the putatively minor developmental changes in adulthood and supposedly universal senescent declines in old age clash with evidence and points of view drawn from the emerging life-span paradigm (compare Horn and Donaldson, 1980, and Willis and Baltes, 1980). Despite such theoretical dissensus, psychologists studying psychometric intelligence have come to agree that global measures such as single IQ scores can no longer be used productively in developmental research, whether on children or adults (McCall, 1979; Schaie, 1979). Instead, the last decade has produced an approach to the testing of a variety of primary mental abilities throughout the life cycle. These abilities, e.g., spatial relations, visualization, verbal comprehension, symbol manipulation, are each identified by one or more specific tests and can be scored individually. In turn, the primary mental abilities—ranging from 10 to 120 in number—have been found to cluster into a small set of higher-order factors or latent mental attributes that are reflected in the primary abilities. According to one widely accepted model, the most central of these latent attributes are fluid and crystallized intelligence (Horn and Cattell, 1967). Crystallized intelligence refers to the universe of abilities embodied in the symbolic culture of a society; it is knowledge and mental skills that a community deems valuable and essential for its maintenance and that are instilled through childrearing and adult socialization in social roles. In broad terms, crystallized intelligence can be identified in abilities to decode a written or oral message, to identify the main ideas, and to retain them for later use; it underlies the capacity to cope with social situations according to the conventional mores of a community; it can be seen in the ability to balance a checkbook or to figure out an IRS Form 1040 each April.

Fluid intelligence is the ability complex that develops earliest. In contrast to crystallized intelligence, fluid intelligence deals with reasoning about novel or unfamiliar material. Because fluid intelligence is seen as the developmental basis for all intelligence, it involves many of the same capacities as crystallized intelligence—abilities to abstract, to solve problems logically, and to cope intelligently with everyday life. Yet it is distinguishable by a unique set of manifestations that are not easily taught by parents or the schools or learned on the job. Rather they are thought to arise through incidental or casual learning and through other influences that affect the physiology and neural processes associated with intellectual development (Horn and Donaldson, 1980:461). Fluid intelligence involves capacities that enable the person to reason with abstract (versus real-life, concrete) symbols, to invent and use alternative (optional, unconventional) classifications or problem-solving strategies, or to visualize novel or hypothetical events.

Both fluid and crystallized intelligence themselves are organized hierarchically as reflections of general intelligence, which is the concept that global IQ scores index. What developmental research missed as it studied the age trajectories of global IQ scores (e.g., Bloom, 1964) was that fluid and crystallized intelligence apparently have different developmental profiles. For example, Horn and Donaldson (1980; see also Schaie, 1979) review a corpus of age-related psychometric research of the last decade that concurs in that fluid intelligence declines after ages 25 to 30, whereas the abilities associated with crystallized intelligence suffer no decline or improve during adulthood (i.e., up to the retirement years). While mental faculties tied to memory also decline as a function of chronological age and do so concurrently with fluid intelligence, there is no apparent causal connection between the two losses in the research they report. The explanation that Horn and Donaldson provide is a multicausal and highly speculative one, inasmuch as the cohort-sequential, longitudinal research base that would be required to sort out antecedent-consequent relationships has not yet been assembled. They suggest that conventional role sequences of adult life provide opportunities for practicing and sharpening the primary abilities subsumed by crystallized intelligence. The research by Melvin Kohn and associates (Kohn and Schooler, 1978) linking the substantive complexity of men's work, their sequences of occupations and job-related tasks, and their profiles of intellectual flexibility illustrates one such long-term arena for learning and practice. However, there may be fewer and fewer contexts within which the incidental learning of fluid intelligence takes place in adulthood. And, the accumulation of brain damage and neural dysfunction as a function of age (the sheer passage of time and increased exposure to the risk of injury) seem to have a greater impact on fluid than on crystallized intelligence. Thus, for example, between the ages of 20 and 60 there is about a 12% loss in brain weight, a decrease (up to 50% in some areas of the brain) in total number of neurons, an increase in neuro-fibrillary tangles and plaques, an increase in the width of brain fissures, and so on. Horn and Donaldson conclude: "The empirical evidence indicates that the abilities of G_f (fluid intelligence) are more permanently affected by loss of brain tissue than are the abilities of G_c, but it is by no means clear why this should be true" (Horn and Donaldson, 1980:480).

One reason may be that the knowledge structure of crystallized intelligence is "overdetermined." That is, it seems to be based on neural structures that contain a higher order of redundancy than fluid intelligence; therefore, loss of brain tissue may not be as crucial to the maintenance of full capacity. Horn and Donaldson's review of neural physiological research suggests a basis for this differential redundancy. It appears that crystallized intelligence may depend upon biochemical structures, or biochemical alterations of neuronal synapses, that seem to be the mechanism whereby information is stored diffusely throughout the brain. Fluid intelligence, by contrast, appears to depend upon electrical networks of firing neurons. Loss of even a small number of neurons would impair the action of an entire network, whereas a similar loss would have less effect on the diffuse biochemical structure. This speculation, tentative as it is, illustrates the close interdependence that has evolved over the last decade between the bioneural and psychological sciences. It suggests that cross-disciplinary exchange among biologists, psychologists, sociologists, and other behavioral scientists will be essential in moving the life-span orientation to intellectual development into concrete and theoretically focused research programs.

Horn and Donaldson's review concludes that age-related declines in the capacities of fluid intelligence are linked to deteriorations in ability to encode (to organize rather than to retrieve) information and to maintain close attention to the details of complex problems or to conceptualize nonstandard relationships. Presumably these age-related, biologically based declines in intellectual skill lie at the root of naturalistic observations by Lehman (1964) and others (reported in Horn and Donaldson, 1980:494). For example, poets are said to peak at age 25–29; psychologists, at age 35–39; rate of output of chemists is highest at age 30–34 and drops by 40–44; peak years for largest annual earnings in most fields is age 50–55. (Lehman's unproven estimates have been challenged by Riley et al., 1968.)

The Life-Span Critique of Developmental Conclusions

Horn and Donaldson reflect an orientation to intellectual development that spans the adult years into old age and highlights the multidimensional, multidirectional, multicausal features of development. However their orientation has been challenged by Schaie, Baltes, and others as anachronistic in light of mounting life-span research (Baltes and Schaie, 1976; Schaie and Baltes, 1977; Willis and Baltes, 1980). Further, life-span research suggests that the predication of a biologically inexorable deterioration of fluid intelligence and related capacities in all individuals in all cohorts does not square with new evidence about the effects of intervention among the aged (those over age 65).

The critique refers to the tendency of Horn and Donaldson to view intellectual development in terms of the normative biological growth model that guided child development and gerontological research throughout most of this century. It finds fault with the emphasis on normative, developmental functions that fail to give attention to the variability of abilities and performances. Such variabilities around the Horn-Donaldson norms manifest not only changes within the individual and his context over time, but also bio-historical changes across samples of different birth cohorts and sociocultural differences among individuals within a given cohort.

Plasticity and Variability in Intellectual Functioning

Schaie, Baltes and their colleagues at the frontier of life-span research on intellectual development emphasize the *plasticity* of intellectual functioning over a person's life: that is, the apparent capacity for marked increases or improvements in mental abilities and performances, as well as for deteriorations, in both fluid and crystallized intelligence until death. They also emphasize that not all individuals age intellectually in the same way; *variability* across persons' age profiles of fluid and crystallized intelligence is substantial, especially across cohorts and across persons with different life histories. Evidence for these conclusions is tentative (e.g., Horn and Donaldson, 1980), but it is becoming firmer as longitudinal cohort-sequential studies and intervention-demonstration experiments are conducted with these ideas as guiding hypotheses.

For example, Schaie (1979) has studied a large number of persons between the ages of 24 and 80. Dividing the sample into seven birth cohorts, he assessed the change in primary mental abilities at three occasions over a 14-year period (1956, 1963, and 1970). He was able to analyze age-related (ontogenetic) changes by comparing change scores for persons at comparable ages (e.g., 35 to 41; 42 to 49); departures from a common ontogenetic pattern across the 7 groups were interpreted as cohort differences. In general, Schaie found that cohort variation was greater than the magnitudes of change in ability that could be attributed to ontogeny (aging) within cohorts. Cohort differences were not uniform across the component primary abilities associated with fluid and crystallized intelligence. Thus, the work challenges the assumption of a universal normative pattern of intellectual performance across the life span; it offers contradictory evidence for the assumption of inevitable and uniform declines in fluid intelligence at advanced ages. (Obversely, it contradicts the generalization that all persons necessarily enjoy stability or improvement in their capacities for manifesting crystallized intelligence.)

There are, of course, many reasons why successive birth cohorts might display different capacities for growth and decline across the various components of fluid and crystallized intelligence. Uhlenberg (1979) has described the massive demographic changes underway in the educational, health, and experiential characteristics of the elderly population in the U.S. It is not at all unlikely, given the overall improvements in levels of education, health, and economic security, that the pattern of future research such as Schaie's will show smaller declines in mental ability at every age in successively more recent birth cohorts. Opportunities for the learning and practice of abilities associated with crystallized intelligence and for the incidental learning and practice of those linked to fluid intelligence have improved and may continue to do so. Improved health care and protection from hazards and injuries may foster greater biophysical, neural capacity at advanced ages. On the other hand, the course of socioevolutionary changes is not inevitable, and the neurons and biochemistry of the brain may be subject to a genetic, evolutionary program for eventual dysfunction and death (e.g., Strehler, 1977). Despite the inevitability of death and dysfunction at some chronological age, the trajectory of experience in reaching this point is varied for persons within cohorts and across them as well.

Another program of research on psychometric intelligence, guided by Baltes and colleagues, has offered suggestive evidence about the plasticity of fluid ability in aged persons (e.g., Baltes and Willis, in press; Willis and Baltes, 1980; see also Denny, 1979; Labouvie-Vief, 1976; and Sterns and Sanders, 1980). Baltes and colleagues have addressed themselves to the underlying potential or reserve for performing various intellectual tasks across the life cycle. They reason that mental abilities must be differentiated from measured performances of tasks that call for the application of ability. On any one occasion, factors such as motivation, fatigue, stress and the like may alter performance and introduce situational "error" into the estimation of an individual's ability. Similarly, across the life span, situational contexts—trajectories of experience—influence performance and add to the interindividual and intraindividual variability at intellectual tasks. Thus, what the analyst observes is some interaction between the "true" or latent ability and the environmental context. But what about ability in some optimum environment, one that is structured to reveal the full latent potential or reserve of ability? In a series of intervention or optimization demonstrations with persons between ages 60 and 80, the Baltes-Willis group has found substantial reserve for improvement in performances at tasks that tap fluid intelligence. Not only do old persons do better at the laboratory tasks, but the experimental treatments seem to encourage generalization to other tasks (tests) as well (see Baltes and Baltes, 1980; and Labouvie-Vief, 1976; for reviews).

Baltes and colleagues have reasoned that psychometric tests are performances that reflect both competence and situational influences such as fatigue, motivation, and interest. Insofar as some primary abilities associated with fluid intelligence decline in some older persons, might these changes be tied to the situational factors rather than to ability per se? In a series of experiments, the Baltes group has attempted to optimize the performances of persons aged 60 to 80 who were drawn from a university community.

One group was tested at repeated intervals in order to give implicit familiarity with the testing situation and the tests themselves. In eight one-hour sessions, another group was given explicit and specific training in the problem solving skills that the tests were designed to measure. Still another group was tested only at the very end of the experimental series and represented a posttest control. With the exception of this last group, the others were tested following the training period at one week, one month, and six month intervals. Sheer familiarity with test taking seemed to improve the scores in the first group. But marked improvements in performances were apparent in the group given explicit training at the rules and logic of tests measuring primary abilities associated with fluid intelligence. Even six months after the actual training had ended, the participants continued to improve at a rate that exceeded the gains in the "familiarity" group. And the former also were able to generalize their new skills to tests of fluid intelligence that had not been the focus of specific training. In related work, tests of response speed also showed the latent capacity for small modification.

These studies have suggested that losses in neural functioning that the elderly suffer may not always impair intellectual performance. Practice at new tasks (or at old ones that have ceased to be salient, e.g., test taking for a 70-year old), motivation, reinforcement, and focused attention are some of the situational factors that have the capacity to mediate the significance of biological changes for the behaviors of the aged. The Baltes group has implied that the elderly have traditionally lived in a context of ill-defined social roles—perhaps, more correctly, a role-less phase of life (Rosow, 1976). Lacking practice or opportunities to learn and sharpen skills, abilities fall into disuse and deteriorate. (The same argument often is made by human capital economists in interpreting the lesser economic returns to investments in education or prior job experience by middle-aged women vis-a-vis men with more continuous work histories; e.g., Polacheck, 1979). This interpretation implies that intellectual performance, and perhaps other abilities and capacities as well, are underlain by a latent reserve or potential that is only partially tapped by conventional social environments. Whereas children and adolescents manifest a greater proportion of this latent reserve, owing to the orientations for achievement and personal development that are built into institutions such as the school and the economy, the reserves of the elderly are less fully utilized or revealed (e.g., Baltes and Willis, forthcoming).

Toward an Integrated Interpretation

This speculation may ultimately provide a basis for integrating the results of the optimization experiments with the work of Horn and others that posits eventual deterioration of function as a normative (typical or average) feature in the aged. The ontogenetic course of latent reserve may in fact peak in early or middle adulthood and decline thereafter because of genetic and other biological influences. But since this is a hypothetical and as yet unobserved developmental limit, more age-comparative optimization research will be required to establish its factual basis. On the other hand, the manifest or actual reserve seems to be malleable in ways that call into question the inevitable and universal correspondence between its developmental course and the limits of latent reserves. In more optimal environments, the trajectory of manifest capacities may continue to rise into old age, long after the latent capacities have peaked.

Speculations of this character are prompting continuing life-span research on the conditions of senescent declines in mental capacity and in independence and mastery behaviors among the elderly (e.g., Rodin, 1980; M. Baltes and Barton, in press). Out of this work has come a series of methodological insights that will continue to reorient developmental research. One obvious illustration is the use of optimization interventions that manipulate the situational contexts within which behaviors and abilities become manifest. Another is the development of new tests and instruments for the assessment of competencies across the full span of life. Schaie and other gerontologists have argued that psychometric instruments that were designed to measure differential abilities in children and adolescents are poorly constructed for use among persons in the later periods of life (Schaie, 1979). That is, the achievement-related contexts within which assessments of mastery and competence derive their originating purpose—i.e., to predict success in school and in the early work career—are largely without direct counterparts in the last third of life.

Schaie (1977/78; see also Labouvie-Vief, 1980) has suggested a life-span theory of intellectual development in which the definition of intelligence changes according to the changes in developmental tasks throughout the successive phases of a typical life course. Fully recognizing that cohort and individual differences in life events may limit the usefulness of a normative approach to conceptual definitions, Schaie then suggests that new tests of primary abilities be constructed to tap these various dimensions. Further, he and others have begun to explore the likelihood that the structure of psychometric intelligence also changes across the life span. For example, the primary abilities that cluster into fluid and crystallized intelligence may undergo a transformation and realignment over time in response to both biological changes and sociohistorical ones. Results from early work seem to bear out this hypothesis and to imply that aging entails qualitative as well as quantitative change in intellectual ability (e.g., Baltes, et al., 1980). Application of structural equation modeling and the use of new computer algorithms for confirmatory factor analysis (e.g., Jöreskog and Sörbom, 1979) have aided this line of inquiry.

Life-span interpretations of intellectual development have animated conceptual and methodological discussions in psychology and fueled theoretical debates. While it is far too early to predict whether this dissensus and scholarly dialectic will catalyze a new behavioral science around life-span issues and methods, the last decade has witnessed a diffusion of new perspectives and methods into developmental psychology. Established concepts and modes of research design are being questioned, and there is a reaching out to related disciplines for help in addressing old questions in new ways. These studies and developments also have brought academic research on psychometric intelligence into a closer relationship with practical or policy-related issues about aging and the elderly—issues like retirement, social security, independent living, and long-term care.

A third arena of current research—the social history of family relations and human development—represents a convergence of attention on a single set of analytical issues under guidance of common concepts. This example illustrates how the life-span approach is helping to organize and redirect a program of inquiry in social history and also across several disciplines. The renaissance of multidisciplinary interest in the historical family, social relationships within the contemporary family, and the role of the family as a context of socialization highlights further potential for the emergence of a new discipline dealing with life-span behavior and development.

THE SOCIAL HISTORY OF FAMILY RELATIONS AND HUMAN DEVELOPMENT

Over the last decade, social historians, family sociologists, developmental psychologists, and demographers have begun to study the family through the themes and propositions of a life-span orientation (e.g., Vinovskis, 1977; Hill and Mattessich, 1979; Hareven, 1978). Increasingly, an interdisciplinary approach under this core paradigm has become the explicit basis on which research problems about the family are defined, variables are selected, and analyses are designed (Elder, forthcoming). This trend has been facilitated by a willingness of the disciplines to expand the frameworks of analysis to include variables normally found outside their separate domains, and by the accumulation of common data bases in machine-readable form that permit integrated analysis (e.g., Thernstrom, 1965; Hershberg, 1981; Hareven, 1978). As a result, sociological understandings of the contemporary American family are being transformed through revisions of stereotypes about the historical family; sociological and demographic insights into family process are revolutionizing historical research; and the psychology of ontogenetic change is adding a biobehavioral dimension to the analysis of family process. Perhaps because it includes so many of the multidimensional, multilevel issues in the analysis of the individual change-social change dialectic, the study of family relations and human development may provide the intellectual context for any eventual emergence of a new life-span discipline.

Reinterpreting the Historical Family

Elder (forthcoming) has observed that as little as a decade ago students of the American family were convinced of two generalizations about the historical trends in family life between the 19th and 20th centuries: that domestic households had become increasingly more nuclear (composed of two parents and their children), and that they had lost many of their economic and human developmental functions. Research in Britain by Laslett (1972), in Austria by Berkner (1972), and in North America by Thernstrom (1965), E.A. Wrigley (1972), and others is contraverting these assertions. This work is revolutionizing our perspective on "the" historical family, and, by extension, recasting our appreciation for continuities and changes in the "embattled" contemporary family. These radical shifts in understanding and in research approaches have been sparked by several developments. One is that manuscript censuses for the late 19th century have become available as research tools; this has enabled quantitative historians, demographers, sociologists and others to synthesize the records of household members over successive enumerations and to link these to administrative and other secondary sources of information about employment, education, and income within the communities of residence. But primarily, it has been the efforts to synthesize processes of family dynamics ("family time") with historical change ("historical time") within the framework of a life-course orientation ("developmental time") that is enabling researchers to begin the difficult analytical tasks of rewriting history and of restating the status of contemporary family life within that historical pattern. Because these revisions are still in their early stages and the data are still being assembled, only the general thrust of the work and preliminary findings can be reported.

Families in the 19th century are not more easily characterized than their counterparts today, our stereotypes notwithstanding. While on average the "historical family" may have been larger than most contemporary ones, household size and composition were highly variable. For example, 19th century households in North America appear to have adjusted their size in relation to changing economic fortunes. In Canadian mercantile centers young adults of working class origin often spent a period outside their parental homes as lodgers in other households, as domestics, or as employees in firms at some distance from their familes (Katz, 1975). In a sense they were part of the parental household economy, because they frequently shared some or all of their income with that unit and returned there after a period away. Elsewhere, the same families that dispersed employable members also took in boarders and lodgers as coresidents as needs arose (e.g., Modell and Hareven, 1973), either because of secular business cycles or because of life-cycle changes within the household (e.g., widowhood).

Thus, families responded to industrialization and the urbanization of the 19th century economy by adjusting their household economic bases in two ways that affected their size and composition: by expanding the sources of income and by limiting the demand on these sources within the household. At some times, households were large and "extended," at other times, "stem," and at still others, "nuclear." There was great variation over time and across households in the strategies that families used to respond to secular (historical) change and to life-cycle transitions and events of their constituent coresidents. In these respects, 19th century families were no different from families today; see, for example, the only on-going longitudinal study of American households, the Panel Study of Income Dynamics (e.g., Duncan and Morgan, 1979). By comparison, contemporary households adjust their labor supply through the life cycle and secular pattern of female labor force participation, family size (birth control), and child spacing. In the Morgan, et al., studies, the chief factors in accounting for the over-time economic status of households were those connected to shifts in their relative sizes and compositions: divorce and separation, additional children, split-offs of sub-household units (Duncan and Morgan, 1976).

Dynamic and Behavioral Approaches

The major change of orientation occurring in the study of the historical family is the shift from an essentially static, structural perspective to a dynamic, behavioral one (Hareven, 1977; Elder, forthcoming). Typological thinking about the "preindustrial," "industrial," and "post-industrial" families, families whose internal structure was thought to mirror faithfully the structural transformations of the embedding economy and society (e.g., Smelser, 1959), has been replaced by transactional approaches in which the family is a dynamic unit over the course of its life, changing its structural features in response to social change and to the life course or developmental trajectories of its several members over chronological time.

For example, Michael Anderson (1971) and Tamara Hareven (1981) use longitudinal, historical data on the individuals within families and households to portray the active role of the family unit in the course of industrialization in both Britain and the American northeast. During the early stages of industrialization, especially in the textile towns of the American northeast, the economic survival of the family was well served by a collective strategy or family plan that sent women to work, withdrew children from school, or aided the migration and job placement of kin as dictated by the changing fortunes of the family. This interplay of "family time" and "industrial time" (Hareven, 1975; 1977) gradually gave way, under conditions of rising affluence and declining family size, to a 20th century pattern of individual life plans that could be pursued without jeopardizing the survival of others. During the 20th century, the earlier patterns of contingency between a person's transition into full adulthood (including the assumption of independent economic roles and the making of a new family unit) and his obligation to be responsive to the episodes of economic misfortunes in the parental household were weakened (Modell et al., 1976). Thus, the conjunction of "family time" and "industrial time" was transformed into one between "individual time" and "industrial time." The tempo of the individual life course was organized by a new set of institutions outside the family that sequenced the roles into and through which persons passed. Age-graded schools, occupational and industrial careers, and promotional schemes by seniority are examples of the emergence of temporizing influences that not only affected the pace of an individual's life but generalized across individuals to form age-graded normative events as cohort experiences.

In this latter respect, the behavioral approach to the 19th century family as both the receiver of historical influences and an active agent in the course of historical change parallels the emergence of "modern home economics" as an orientation to the study of the contemporary family (e.g., Becker, 1965). Studies of investments in childrearing, in the labor supply of mothers, and in schooling (e.g., Kaestle and Vinovskis, 1979) in 19th century America cast the family as a set of decisionmakers optimizing their utilities through production, reproduction, consumption, and resource allocation in a changing social and economic environment. What is striking about the new family history and the new home economics (really a version of human capital theory applied to the production and consumption time allocations associated with domestic vs. market labor decisions and childrearing) is that both behavioral theories have such underdeveloped conceptions of human ontogeny. Perhaps this weakness, or lesser theoretical development, is understandable in the reconstructions of 19th century behavior, because of the absence of appropriate data. In the case of human capital theories of contemporary domestic economies, however, this conceptual shortfall is a challenge for the future. In this regard, it seems essential that economists become a more central part of the multidisciplinary discussions of life-span behavioral processes. Longitudinal data on individuals within household aggregates, such as those being collected by the economist, Morgan, are also indispensable to this endeavor.

Life-span, behavioral approaches to the study of historical families responding to and shaping the course of industrialization are reshaping current debates about the social functions of schooling and family in the political economy. New data from manuscript censuses and reconstructed life histories challenge the social criticism of "radical economists" and neo-Marxian sociologists that the schools in the 19th century were used by capitalists to control and shape working class and immigrant behaviors into forms that were useful to entrepreneurs (e.g., Bowles and Gintis, 1976; compare Kaestle and Vinovskis, 1980). By contrast, the picture of school enrollment and its relationship to the economic activities of families and the life courses of individuals is becoming much more complex in new historical research. Studies show, for example, that school enrollment of older children was common prior to the middle and late 19th century and the spread of industrialization in America (e.g., Kaestle and Vinovskis, 1980). In addition, many of the "modern" attributes of the family (e.g., "companionate" social relationships) also may have predated their alleged "cause" (Wrigley, 1977). Thus, historical, life-span research is forcing a revision of thinking about the modern family and its relation to the political economy, if only because social criticism of contemporary institutions is predicated on apparently false historical assumptions that only now are coming to light.

History and the Changing View of Modern Families

Dynamic, behavioral thinking about the inter-connection of social change, individual change, and change in family structure and process is challenging more than our stereotypes of the historical family. It is revolutionizing the study of the modern family as well (Elder, forthcoming). For decades sociologists and demographers have used the concept of the "family cycle" to describe and analyze regular changes in the social relationships and orientations among family members as a function of temporal shifts in family composition (Loomis and Hamilton, 1936; Glick, 1947, 1977; Glick and Parke, 1965; Duvall, 1971). That is, the family as a social aggregate was thought to assume certain universal behavioral features as a consequence of its structural properties and transformations of them. For example, Hill and Mattessich define "family development" as

> the process of progressive structural differentiation and transformation over the family's history, . . . the active acquisition and selective discarding of roles by incumbents of family positions as they seek to meet the changing functional requisites for survival and as they adapt to recurring life stresses as a family system (1980:174).

Historically, the "family history" to which Hill and Mattessich refer was conceived as a series of sequential, static, age-graded types of family "structures": for example, marriage and the dyad, birth of the first child and the triad, youngest child leaves home and the empty nest, retirement and ultimate dissolution of the marriage through death of one spouse. Demographic regularities in ages at marriage and in child spacing have provided the age-graded character to the family cycle, since the stages or phases of family life (structure) that it distinguishes are predicated on markers of "family time" such as age of oldest or youngest child, age at retirement, age at death of spouse.

Because of the life-span orientations, family researchers now recognize that the concept of the family cycle has been ahistorical, static, culture-bound, and unduly focused on the impact of children on the parental relationship. To be sure, the concept has aided the analysis of longitudinal change in behavior, but it was based on typological thinking, and on assumptions about the prevalence of marriage and the nuclear family and of the durability of marriages throughout a lifetime. Glick and Norton (1977) project that among contemporary young marriages, forty percent will end in divorce. Of those who become divorced, between three-quarters and five-sixths will remarry and remain in that relationship until the death of the spouse (Glick, 1977). Together with the greater stability of marriages in older birth cohorts, today's marital and remarital patterns attest to the preferability of married life, for about eighty-four percent of all families in 1975 were husband-wife families (Glick, 1977). At the same time, the recycling of adults through marital relationships and the accumulation of children exposed to divorce and either long periods of single-parent family life or second or multiple families have increased markedly over recent decades. Only 67 percent of all children under 18 live with their own once-married parents (Glick and Norton, 1977). In this context, the static typological model of the family life cycle has little scientific utility.

Hill and Mattessich's definition of family development is one heuristic effort to revise the study of the modern family that incorporates the elements of a life-span orientation and is flexible enough to apply across the historical experiences of different birth and marital cohorts (see Clausen, 1972; Spanier and Glick, ND). The newer approach views the family as a constellation of individuals' life courses in some mutually contingent relationship and in the context of evolving historical circumstances. The pertinence of research on family life during the industrial revolution for the conception of the modern family is that historical circumstances are themselves the outcome of the interplay of individual developmental processes, of family or collective responses to the historical moment, and the opportunities and constraints of historical events and contemporary institutions.

Glen H. Elder, Jr.'s description of families in the Great Depression illustrates this. Elder (1974; 1978; 1980) has conducted social psychological research on the reciprocal relationships between historical and personality changes using two studies of San Francisco Bay area children, born in the 1920s, as they have grown into adulthood. His work illustrates the "cohort sequential" method of longitudinal research, for it contrasts the life courses and personalities of individuals within two birth cohorts as they have aged. In each cohort, Elder explores the differential impacts of relative economic deprivation associated with the Great Depression and of mitigating influences associated with military service in WWII, subsequent career security, and other adult life events. One cohort, drawn from the city of Oakland, were adolescents during the depths of the depression. A second cohort, from Berkeley, was born later and spent its childhood in the depression, adolescence in the war years, and adulthood during the post-war economic boom. Effects of sudden economic hardship and resulting family distresses were more visible in the Berkeley cohort, for whom a greater portion of childhood was lived during hard times. The timing of this deprivation, relative to developmental age, placed the Berkeley children at greater risk to cumulative disadvantage than the Oakland children. Across the decades of longitudinal data, Elder observed men from households that suffered large economic losses—irrespective of social class—to voice concerns for security and to value financial conservatism. But these attitudes and related behaviors were much less salient for men with stable work histories and marriages, demonstrating the moderating influences of proximate life events among men of equally deprived depression backgrounds. Neither were all men of either cohort equally affected by the depression. For example, some lived in families that lost relatively little; some had fathers whose sudden decline in earning power altered the pattern of father vs. mother dominance and the strength of the father as a role model for his son. Others came from households where creative coping with distress and collective sharing of new responsibilities were sources of family solidarity. In each of these particular instances of differential loss and of family response, Elder found different manifestations of the depression—manifestations in anxieties and mental health and in values for conservatism or risk-taking.

One instructive feature of Elder's long-term program of research from a life-span perspective is his demonstration of the importance of cumulative life history as a tool in analysis of differential outcomes of the depression. To be sure, he was able to document different manifestations of the depression in the pre-adult lives of the Bay Area residents and in the interaction between developmental age and the onset of economic hardship. In addition, however, Elder emphasized that the developmental consequences of these variable impacts of the depression were even more varied in adulthood. For example, adolescents whose family's relations were heavily strained by the father's loss of substantial earning capacity and related esteem, and whose mothers often assumed a position of dominance, frequently suffered anxieties and doubts about personal competence. Yet in those instances where the son was able to move away from the parental household rather quickly, as was the case for many of the Oakland boys who were mobilized into WWII, long-term effects of these experiences in youth were offset by fresh starts in new settings. Others, who went to college, failed to evidence any career-related disadvantages, inasmuch as they were the most able to avail themselves of the expanding economic opportunities of the post-war boom and to establish the actuality of their competence.

In summary, Elder's continuing longitudinal research within these two cohorts reflects many of the themes and propositions of the life-span orientation. For example, developmental research must be historical and situational insofar as historical events precipitate change in the course of lives, both between and within cohorts. And, developing individuals are agents as well as receivers of historical change. (By implication, Elder's work suggests that there may be only a limited set of generalizations that are ahistorical, i.e., as true in 1990 as in

1980, that behavioral scientists can make. This may differentiate the inherent nature of social science from that of the other sciences.) The chief illustrative value of Elder's work may lie in its description of the ways in which a single historical event interacts with the variegated circumstances in persons' pasts and futures to increase the likelihood both of change across the course of life and of individualized life trajectories of adults from seemingly similar social and historical origins.

Usefulness of the Family as a Unit of Analysis

Viewing families as co-residing individuals complicates the study of the family, for it forces the analyst to see a family unit as a potentially unique entity. Each individual is at his or her point in personal developmental time, the significance of which is cast in terms of a cumulative life history. The aggregate co-residential unit can change in time because of dissolutions of marriages, remarriages, or other compositional changes that imply a dynamic situational context for these individual life courses and their combinatory outcomes. Then, too, there is the impact of sociohistorical change that becomes manifest in potentially unique ways.

Sociological and economic research on cohort marital fertility and female labor force participation supports this perspective (e.g., Easterlin, 1980), as does Alice Rossi's (1980) examination of how the hormonal and physical changes (or differences in the degrees of biological change) in middle-aged parents of adolescents alter the qualities of family life for both parents and children. Rossi's study is one of the few by sociologists to incorporate social and biological influences on human development and to recognize the dialectical dynamics of simultaneous change in children and their middle-aged parents. Socialization in families becomes a two-generation process that is continually underway.

Whether the next decade of life-span research will continue to see the family as a useful unit of analytical distinction is now unclear. Incorporation of the life-span approach into family research raises the possibility that "family development" may prove to be nothing more than the interactive combination of the individual developmental trajectories of co-residents. Put another way, one challenge of the new perspective for sociologists and others who have traditionally used structural features and "stages" of family development as analytical tools is to demonstrate that the aggregate or structural approach remains viable, given the increasing diversity (and recognition of it) of both individual patterns of development and the histories of individual families or co-residential units. This challenge is not unlike the one before students of adult development who have tended to use stage or phase models of personality change over the life course (e.g., Gould, 1978; Levinson, 1978; Vaillant, 1978). Brim and Ryff's (1980) generic effort to identify and classify how varieties of life events—biological, social, historical, and psychological—shape and reform the personality within both normative and nonnormative trajectories of experience may provide a necessary conceptual bridge between developmental research involving "family cycles" and research on the socialization of children and their parents.

The Multidisciplinary Future of Family Research

Life-span research on the historical family and its functions as agent of socialization and of social change is providing new opportunities to reevaluate the modern family. In some ways there appear to be greater historical continuities, especially in economic and demographic functioning, than hitherto appreciated. In other respects, massive cohort and historical discontinuities are becoming more apparent (e.g., Brim, 1980). Life-span research on the family is inherently multidisciplinary because of its focus on individual change, social change, family process, generational relations, and bioevolutionary change. On a reduced scale of personality systems and social systems, it provides all the essential elements of the individual change-social change paradigm that underlies the entire intellectual scope of life-span development issues. As behavioral scientists carry forward the scholarly momentum of the last decade, as economists work more closely on family-related processes with historians, sociologists, and developmental psychologists, the foundation for new disciplinary breakthroughs and multilevel theory-building may be prepared. In any case, both multidisciplinary and unidisciplinary social science appears to be most cumulative when there is a concrete link between academic scholarship and practical problems (e.g., House, 1977). Certainly the contemporary family, in all its myriad forms and transformations, provides that context.

PUBLIC POLICY AND THE LIFE-SPAN APPROACH

Life-span orientations in the social and behavioral sciences have practical as well as academic significance. This view of constancies and changes in behavior and development across the whole of life is debunking stereotypes about the aged, adults, and adolescents and children. It is questioning the longstanding assumption that age is a reliable predictor of behavior. It calls attention to the variability across persons in the temporal course and consequences of biological, psychological, social, and historical events. It emphasizes the malleability of personality and behavior in persons of all ages. And, it underscores how changes in the societal and cultural contexts continually alter the situations in which successive generations and cohorts live out their lives. Research guided by this mode of thinking is beginning to accumulate a base of findings that ultimately might be applied to social problems and public policy. Meanwhile, the life-span approach is altering the frameworks within which issues of public concern are cast and discussed.

ALTERING THE FRAMEWORK OF AGE-RELATED POLICIES

Bernice Neugarten (1979) has suggested that research on human development over the life span may move us toward an "age-irrelevant" society: a set of institutions that responds primarily to abilities and interests rather than to age. Such a society would feature social welfare and legal entitlements that are tied not to chronological age but to individuals' preferences, needs, and capacities; it would also include appreciation of the potentials for change and development in ourselves and others that would not be diminished by age-based stereotypes.

Neugarten and others who speculate about the coming of an age-irrelevant society have pointed to recent and important demographic shifts that may encourage such social changes. One is the rapid growth in the absolute size of the elderly American population. Another is the remarkable recomposition of its socioeconomic and health-related characteristics, which is forcing us to recognize differences between the "young-old" and the "old-old." Persons reaching age 65 in the 1980s are ever more educated, healthy, and long-living, and perhaps more economically secure. Their cumulative life histories are less marked by the Great Depression and reflect the benefits of a generally sound economy and of pervasive public health and medical care in the post-WWII years during which they spent their entire adulthood (Uhlenberg, 1979). These facts imply that we should think of this and adjacent birth cohorts as qualitatively different from the elderly who were their parents—the generation born at the turn of the century whose adult lives were bisected by the Great Depression.

Furthermore, it is among these recent older Americans that optimization research shows apparent potentials for performance that we once assumed were not within the capacities of the elderly. Margaret Baltes and colleagues have demonstrated that residents in nursing homes can become more functionally independent and healthier when environments and staff-resident interaction patterns are consciously designed to promote these behaviors (see Baltes and Baltes, 1980, for a review). Judith Rodin (1980), in exploring the relationship between the stresses engendered by the elderly's residential and social settings and health, finds that instruction in practical problem-solving has enduring effects in improved mental health and longevity. Research on psychometric intelligence suggests that constructive environments, practice, and encouragement can offset or reverse losses of mental functions associated with biological senescence (e.g., Baltes and Willis, 1981). Finally, we are discovering the developmental significance of "wisdom" as a performance characteristic in many elderly (Birren, 1978; Clayton and Birren, 1980). Wisdom seems to involve a "mastery of (life's) situations that have resulted in emotional and cognitive overload . . . a balanced view of investment in self as well as in others . . . having moved from concerns with things to ideas and from actions to meanings" (Birren, 1978). Wisdom has apparent importance for cross-generational relationships, and as such may be an evolving developmental characteristic in elderly populations of the future.

Another demographic fact whose implications for public policy can be interpreted within a life-span perspective is the increasing size of future elderly populations relative to the sizes of their younger contemporaries. What these older persons can and want to do has important implications for the costs of their health care, housing, and social security at the public expense—an expense borne largely by younger workers. One implication of the life-span approach is that such issues should be discussed in terms of meeting the needs of specific persons, irrespective of age. Categorically targeted assistance programs for the aged—presently designated as age 65 in many federal programs—may actually deny services to those most in need by dissipating the available public funds. Those most in need may include many of the very oldest citizens but also children and younger adults. In an "age-irrelevant" society, need based on functional capacity rather than on age *per se* would be the criterion for public assistance (i.e., Neugarten, 1979). The challenge that life-span thinking places before the public forum is how limited capacities can be defined and optimized at all ages. But it is a double challenge, since the life-span approach seeks to uncover biological and environmental limitations as well as latent reserves for developmental change. It is just as false to assume that each person can heal or develop herself without assistance from others as it is to use age as a basis for what we expect ourselves and others to be able to do. Life-span social and behavioral research in the 1980s faces an exciting future insofar as it can assist in discovering the developmental potentials of citizens and in defining an equitable basis for public assistance that reflects functional need.

Life-span research also underscores the importance of reexamining public programs that are directed at age groups and rethinking their relationship to human development. One example is social security, for the adequacy of its funding depends upon eligibility criteria and the relative size of contributing and claiming groups. Recognizing that many persons—perhaps ever-larger fractions—over age 65 could remain productive economically if their unique capacities were optimally developed and maintained, legislators may raise the age of mandatory retirement. At the same time, the demographic legacy of the "baby boom" and the stabilization of population change is a large proportion of middle-aged Americans over the next decade. Promotional prospects and incentives for socioeconomic advancement could be reduced, especially in the middle and later years. Depending on the growth rate of the economy, increased fractions of job-seeking women and adolescents and the cry for equity in the distribution of work across minority groups may prompt more job sharing and episodic work histories for all workers. Work histories punctuated by periods of school attendance or other activities could become more common. Such hypothetical possibilities illustrate another life-span theme: individuals are active agents in their own development. Public policies about employment and retirement, for example, can have a major impact on the context for and course of human development—development that can be altered by legislation from decade to decade and legislation that is informed by increasing knowledge about the plasticity and variability of development.

Life-span thinking influences the discussion of public policy through its focus on long-term effects in a changing social and historical context. Many of our policies about public education, for example, assume a close connection between what is learned by the young—how it is learned, student behaviors that facilitate learning and acceptable performance—and adults' productivity and achievement in the economy and society. These policies assume both that education through adolescence is for life, and that the curriculum will not become irrelevant or out-dated before age 55 or 65 when the next generation of productive workers and citizens replaces the unproductive and obsolete generation.

A life-span orientation strips the validity from many of these assumptions. From the perspective of career preparation, the formal education of workers over the next decades may of necessity be continuous throughout adulthood. Recently, the American work force has suffered periodically from over- and under-supplies of professionals and skilled labor. Retraining of adults for second or third careers could help mitigate the imbalances between supply and demand (by shortening the lag between the timing of need in the economy and the preparations of adolescents and young adults whose own career educational choices often anticipate the wrong configuration of future demands). Demographic changes in fertility that will decrease the relative supply of youthful new workers may encourage career reeducation as a more regular feature of adult life. Should older adults return to the classrooms in significantly greater numbers, this will make it necessary to alter the designs of curricula to suit the social and psychological characteristics of the new students. Modes of learning, the scheduling of classes, the most effective teaching techniques, the assumptions that textbooks make about levels of preparation—these and other components of the educational process that are now predicated on an adolescent and young adult student body that is highly age (and cohort) homogeneous will require reassessment.

Aside from career-related functions of education, a life-span approach to the design of educational institutions and facilities would recognize that life-long developmental potentials create a demand for multiple educational objectives. To be sure, continuing academic and practical training of older adults can be a good economic investment, given the apparent latent capacities of older persons who want to work to do so productively. At the same time, education and training that are focused on work-related goals may not be as relevant to as many older persons as to younger ones, given developmental shifts in primary interests and motivations. But age itself is not the key factor. Depending on the momentary state of the economy, one's "stage" of family development, and a variety of other factors that bear little or no relation to age *per se*, one's interest in formal education may be avocational.

The demographic consequence of current American fertility will provide a less rapid replacement of older citizens by youthful ones. In that context, continuing adult education will become increasingly important. No less than in past decades, the education of one's youth becomes obsolescent in the rapid pace of change in modern society. But without a large supply of newly educated youth to replenish the stock of talent and information, the nation will have to turn to its large supply of adults and older persons. Life-span social and behavioral science should be challenged in the next decade to identify the limits and potentials of development across infancy, childhood, adolescence, adulthood, and old age that can inform policies for mobilizing the talents of the nation and for achieving a high order of well-being in its citizenry.

PROSPECTS

Life-span research in the social and behavioral sciences is challenging old ways of thinking about the course of human development and of aging. Whether or not a new behavioral science of life-course processes—a new discipline—emerges over the next decade in response to these developments, the promise of the next five years is for closer contact and collaboration among several existing disciplines, especially psychology, sociology, history, economics, anthropology, and biology. Working within the emerging common themes and propositions of a life-span orientation, there likely will be a productive division of labor. For example, psychologists may devote themselves most intensively to uncovering ontogenetic processes and behavioral sequences that seem to have more general manifestations across historical moments. Sociologists and anthropologists may concentrate on understanding how, when, and where age becomes a basis of social organization—how events become more or less age-related or age-graded; when and how a society becomes "age-irrelevant." Economists and historians may seek an understanding of historical episodes and cohort cycles that both reflect and mold human development as a dynamic life-long process. Biologists may pursue cellular aging and the science of neural processes as reflections of historical changes in species longevity and cohort succession. What should be different about the next five years is not that psychologists will become historians or that sociologists will be certified as biologists. Rather a conscious division of labor and the recognition of common perspective should yield at least more sophisticated and ecologically valid biology, sociology, psychology, and so on.

To realize the broad academic and practical potentials of the life-span orientation over the next decade will require a new programmatic research agenda so that trustworthy generalizations can cumulate under the guidance of the new perspective. Insofar as one cohort potentially ages or develops according to its own unique historical and biological circumstances, scientists must be able to compare the experiences of two or more cohorts. Replications of studies—repeating the same investigations with the same or equivalent methods—must become more common in order to monitor the course and effects of historical and institutional change on development and to assess the reciprocal influences of individual and social changes across successive cohorts. Longitudinal designs and the follow-up of panels of cohort samples through their life-time are essential for life-span research. Intervention research and historical and cross-cultural studies must be undertaken in order to define and understand the limits and potentials of the human condition as it interacts with and transforms its context over time. This is a comprehensive research program, one involving the collaboration of several disciplines and profiting from the special skills and techniques associated with each. It calls for a sustained temporal commitment from these colleagues, for the organization and maintenance of longitudinal, cohort-comparative projects are both demanding and long-termed. Obversely, it requires a stable base of research funding—one that recognizes both the benefits of long-run programmatic effort and the need to reassess and update the base of knowledge routinely.

It has been suggested that the social sciences were consolidated intellectually in the U.S. during WWII at a time when they were challenged to face the practical needs of the nation at war (e.g., House, 1977). That was a period of cross-disciplinary cooperation. The emergence of renewed interest in multidisciplinary scholarship within the common themes of the life-span approach is one sign that the social sciences again may be poised to advance. Surely the practical challenges of the 1980s that might focus this sense of new scholarly vision and common pursuit are no less substantial than those of the 1940s.

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5 Statistical Measurement of Social Change[1]

Albert J. Reiss, Jr.

SUMMARY

Many major research and policy issues require the statistical measurement and analysis of social trends. In the United States, government officials, businessmen, scholars, and the larger public are asked to address problems associated with patterns in such areas as crime, the birth rate, health care, residential change, and the like. The accumulation of information about social conditions as well as advances in analytic techniques and concepts of change have greatly extended the ability of society to study itself, its past, and a range of possible futures.

This essay describes the need for measuring social trends, illustrates the development of new concepts and the need to monitor the assumptions on which projections of future conditions are based, and describes cohort analysis, one of the powerful methods used to understand the dynamics of social change. The chapter suggests areas in which models and measures of change are most promising and describes how the organization of the national statistical system affects the way that we understand social trends in the United States.

A central question addressed in this chapter is how we are to decide which aspects of society to monitor and where new measurement programs and models are needed. The present body of social measurement in the United States is predicated on serving two main interests. Measures derive either from the theories and models about social change that are formulated by social scientists or they derive from attempts to illuminate the problems and evaluate the policies and programs that are important to public or governmental interests. Considered together, these two criteria suggest that the payoff to the commitment of resources will be especially promising when interests in explanation and in public policy converge. Three areas of inquiry in which the priorities of government and social scientists intersect are the measurement and analysis of the well-being of individuals and groups, social inequality, and indicators of science and technology.

If we are to understand social change and use that understanding for policy and prediction, we need to distinguish real changes from apparent changes. This ability can only be derived from an extended period of observation of social conditions and events; a continual collecting of time series, and monitoring of concepts, measures, and assumptions; and analytic tools that can identify, dissect, and explain the components of social trends.

The statistical measurement and analysis of social change depends on more than careful attention to data, measurement, and analysis. Our capacity to understand

social trends rests heavily on public policies and on the organization of research and development in social measurement. Among the factors that affect our ability to observe and analyze changes in social conditions are the manner in which data are produced, distributed, and reported. Understanding social change and using that knowledge are impeded when information about social conditions is collected without regard to its use for monitoring long-term trends or with inadequate attention to the comparability of measures across time or across different governmental jurisdictions. The chapter recommends the continuation of old measurement programs, the replication of previous studies, and the accumulation of existing measures of social conditions.

INTRODUCTION

Questions about social change often appear deceptively simple. People, businesses, and governments ask if neighborhoods are more or less safe from crime than they used to be. Administrators, parents, and employers want to know whether high school graduates are learning more or less than previous generations. Organizations concerned with inequality want to know whether the income differences between blacks and whites, and between men and women, have narrowed or expanded. Governments at all levels must deal continually with issues related to social changes.

Many major political issues are the consequences of continuing social trends or they stem from attempts to manage what are believed to be trends. In the United States, government officials, scholars, and the larger public are asked to address problems associated with changes in such areas as the availability of trained employees, the quality of schools and housing, the extent and consequences of residential migration and unemployment, and the efficiency of delivering public services. They also want to know whether the rate of social change is accelerating or decreasing. Is the crime rate going up at an accelerating pace or is the inner city losing population at a faster rate each year? To address these problems—to observe and analyze changes in these conditions and on their rates of change—requires the use of statistical indicators.

Consider, for example, the needs for information and analysis that the problems of energy will impose. How are we to monitor and assess changes in the sources of supply and demand, and in the rate of depletion of energy resources? How will energy changes affect population migration, life styles, and standards of living? What are the consequences of different energy sources for the environment, for the cities, and for social and recreational needs? Statistical data are needed to assess the availability of and demand for alternative sources of energy and the probable consequences of different mixes of their uses (Unseld, Morrison, Sills, and Wolf, 1979).

Yet statistical data alone are insufficient. To deal with the policy demands of a changing society, governments must have reliable data on recent social trends, measures of the components of change, and ways to understand and analyze the data. Without careful attention to all three components—data, measurement, and analysis—we may fail to recognize changes and trends that are taking place or, alternatively, see change (or stability) where none exists.

THE NEED TO MEASURE SOCIAL TRENDS

Mark Twain is credited with the remark that everyone talks about weather but nobody ever does anything about it. Weather, he wrote, is "necessary to a narrative of human experience. . . But . . . it ought to be the ablest weather that can be had, not ignorant, poor-quality, amateur weather. Weather is a literary speciality, and no untrained hand can turn out a good article of it." Observations about stability and change are as fundamental to our generation as observations of the weather were to Twain's. Yet despite the importance of understanding what is and is not changing around us, we stand, at times, as helpless as Twain's generation before the weather.

Twain's caution that we need "the ablest weather that can be had" can also be applied to the study of social trends, a subject that has attracted a growing audience within the social science community in recent years (Bohrnstedt, 1980). This approach represents a change of focus from a preoccupation with attempts to understand society as if it were static or timeless to a concern for discerning and measuring social change over time.

It is precisely because social change is so pervasive that everyone is his own interpreter, validating and moderating his own observations of social trends. But this familiarity does not guarantee accurate interpretation. Common sense can mislead us because it is forced to rely on incomplete evidence or partial explanations. In addition, common sense "quickly accommodates to what it sees happening, and hence does not know what to be surprised by" (Keyfitz, 1980:62). Very often, the clues we receive about social phenomena disguise or misrepresent what is actually occurring. Part of the utility of the formal study of social trends lies in exposing the intuitive wrong, even if the argument appears obvious to our accommodating perceptions.

Regular observation and description often provide pictures of social trends that differ markedly from apparently reasonable interpretations based on a portion of the needed information. Two examples will help to illustrate how social science analysis can challenge common inferences and reveal misperceptions: the first concerns fears about increasing marital instability attributed to a perceived rapid escalation of divorce rates; the second example pertains to an apparent lack of progress in reducing income differences between whites and blacks.

MARITAL INSTABILITY

The effect of major social changes on the structure and functions of the American family has received considerable attention in both the popular press and scholarly publications. A central issue is whether the nuclear family is unstable or even disappearing, as a result of the dramatic rise in the divorce rate during the last thirty years. Between 1960 and 1978, for example, the annual divorce rate—the number of divorces per marriage—more than doubled.

What we conclude about this increase, however, depends in part on the points of time we choose to compare. An examination of the divorce rate in the United States over the past century corrects an impression based on divorce rates in the more recent past. The recent increase represents the continuation of a trend which has been going on at least since the Civil War (Preston and McDonald, 1979). Figure 1 shows a steady increase in the divorce rate since 1870, with major—but temporary—deviations from this gradually rising trend. One of these departures from this trend affects our conclusions about recent changes in the divorce rate. After the rapid increase following World War II, the divorce rate fell below the level that could be expected on the basis of the long term trend. The marriages of couples who produced "the baby boom" appeared to remain intact in far greater numbers than expected. The relatively low rate of divorce continued until about 1960, when it began a slow and then a dramatic increase that has remained for more than a decade. Comparisons between the divorce rates of the 1970s and those of the late 1950s, therefore, contrast the highest divorce rates in recent times with rates that run counter to long-term trends. Thus, recent increases viewed solely in the light of this

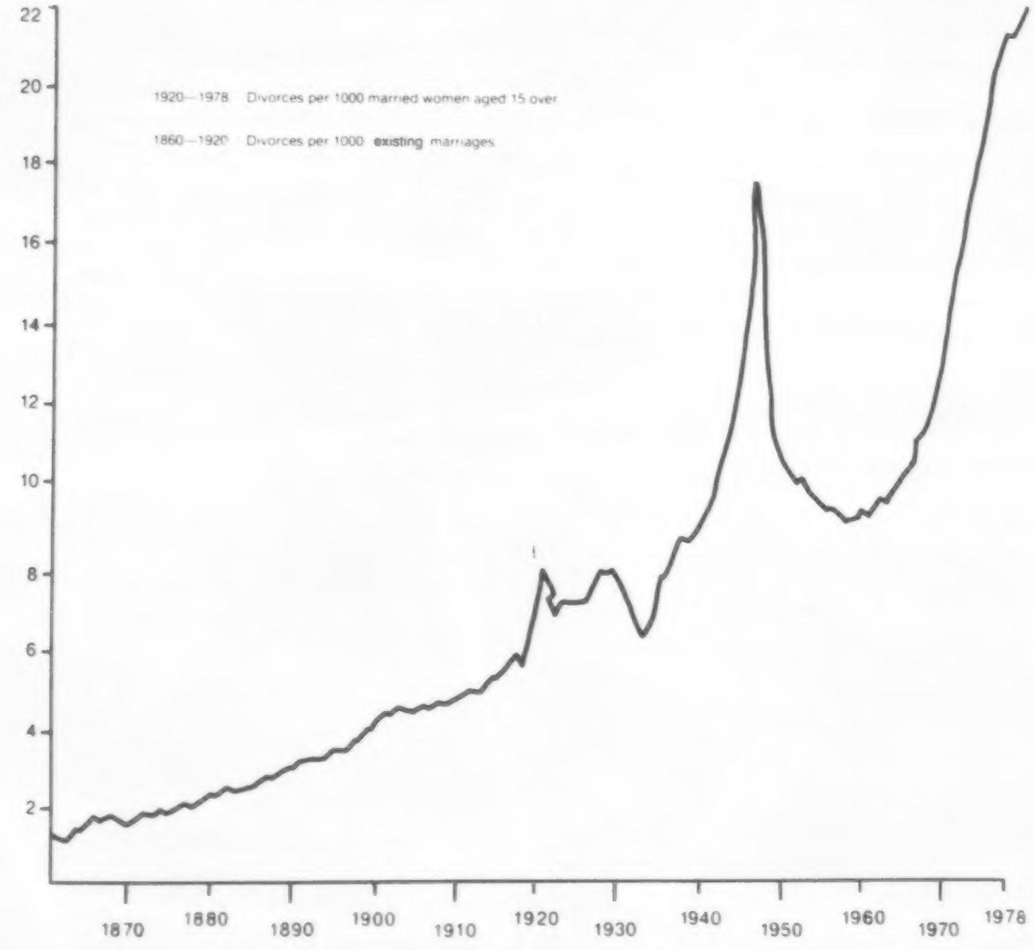

Figure 1. Annual Divorce Rate for the United States, 1860–1978.

Source: Paul H. Jacobsen, 1959: Table 42; U.S. National Center for Health Statistics, 1973: Table 4; U.S. National Center for Health Statistics, 1980: Table 2. Reported in Cherlin (forthcoming).

abbreviated part of the historical record are somewhat exaggerated, as are conclusions about society that are based on them (Cherlin, forthcoming).

It should also be noted that the annual divorce rate represents the cumulative experience of couples whose marriages may span as few as several months or as many as seven decades. The annual divorce rates we record today do not, therefore, reflect only recent changes in society. Instead, they reflect changes that have taken place over many years but which are poorly detected in contrasts between short periods of time or atypical rates. In order to obtain a fuller understanding of the changes in the divorce rate, it is useful to examine changes in the proportion of marriages contracted in a given year which have ended, or can be projected to end, in divorce (Preston and McDonald, 1979). Figure 2 shows that marriages contracted in 1970 were six times more likely to end in divorce than marriages begun in 1860, but only about 20% more likely to end in divorce than marriages contracted in 1960. Thus, while the chance of divorce for a couple married recently has increased, the rise has not been as rapid as the annual divorce rates would lead us to believe.

BLACK AND WHITE INCOME DIFFERENCES

Misinterpretation of trends can also be due to inadequate disaggregation of the data. Consider, for example, the difference between average family incomes of blacks and whites. In 1969, the median reported income of black families was 61% that of white families; in 1978 it had fallen to 59% (Hill 1980). Do these data mean that blacks fare worse now than they did at the beginning of the decade? Or that society has made little progress in eradicating income inequalities?

The problem with these conclusions is that they invite confusion of family income with individual income. If family incomes are compared, the picture is the one that is sketched above. However, if the average incomes of black and white *workers* are compared, the conclusions are very different. For the gap between individual incomes has narrowed: on the average, earnings of blacks have risen faster (in constant dollars) than the earnings of whites. In 1959, the average income of black men who held jobs was only 58% that of white male workers; in 1977 it had risen to 73%. Black women who held jobs earned 64% of the wages of white female workers in 1959 and 95% in 1977 (Farley, 1980).

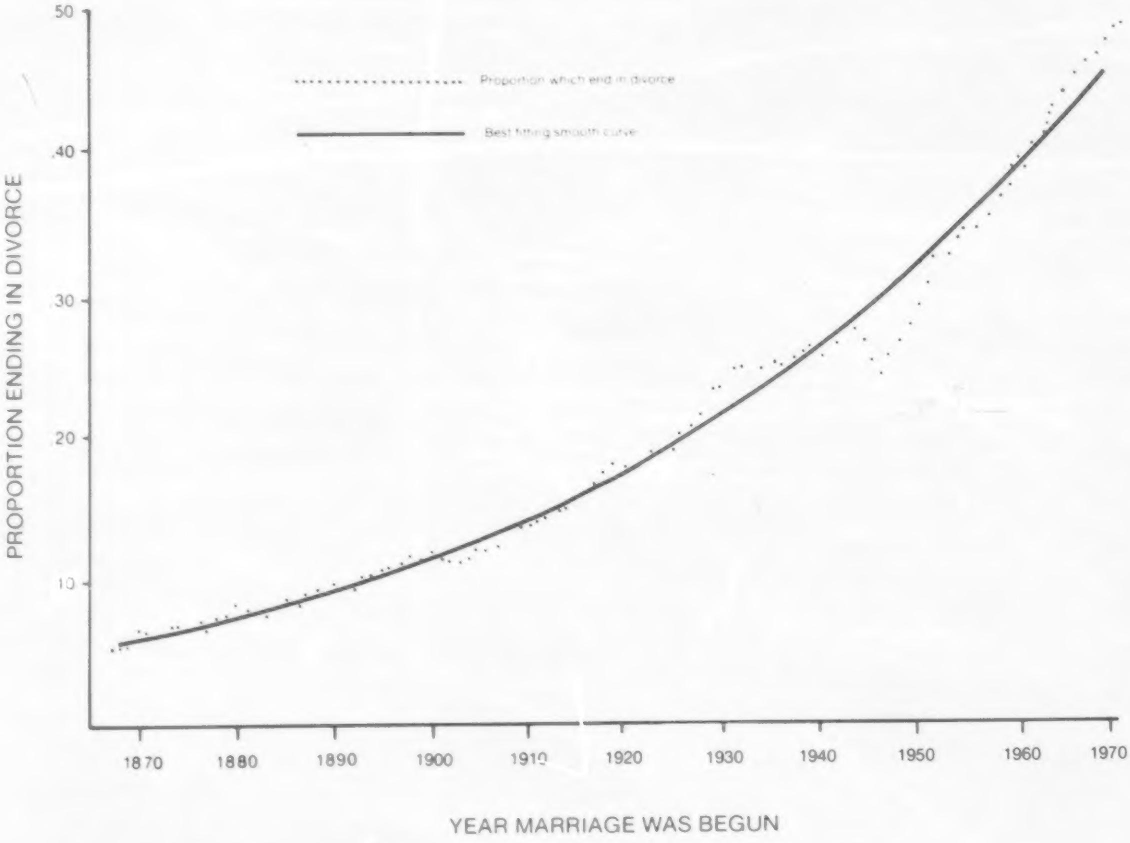

Figure 2. Proportion of Marriages Begun in Each Year Which Will End in Divorce, 1867 to 1973.

Source: United States National Center for Health Statistics, 1980; Preston and McDonald, 1979 as reported in Cherlin (forthcoming).

The particular puzzle of widening differences in family earnings and declining differences in individual earnings can be explained by two trends in the composition of families. First, and probably more important, the past decade has seen an increase among both blacks and whites in the proportion of families headed by females, but this increase has been more pronounced among black families. Because of the generally lower earnings of women as compared to men, families headed by females tend to have lower incomes than husband-wife families. The second trend is that white and black families have been changing—in opposite directions—in terms of the number of wage earners in the family. Among whites, the proportion of families with two or more wage earners increased from 54% to 57% between 1969 and 1978, whereas among blacks the proportion dropped from 56% to 47% (Hill, 1980).

In order to understand the black-white income gap, we must go beyond the surface of the statistics to address questions about the units of analysis (e.g., family or individual) and about earnings, employment, family composition, and family size. Comparisons based on a single statistical series may present a misleading impression of the nature of the change in the relative incomes of blacks and whites.

If we are to have an enlightened understanding of social change and use it for making policy and predictions, we need to be confident that we can discern real changes from apparent ones. This confidence can only be derived from extended observations of social conditions and events; continual monitoring of the appropriateness of concepts and measures; and analytical tools that can identify, dissect, and explain the components of social trends. The evolution of concepts and measures of social conditions and the need to continually monitor the assumptions on which projections of social trends are made are discussed in the following section, and the use of one analytic approach to understand social change is illustrated.

CONCEPTUAL AND ANALYTIC APPROACHES

Social scientists must remain alert to the fact that social change may render the concepts and measures used to understand social trends less appropriate or even obsolete. Similarly, the assumptions on which projections of the future conditions are based can also become outdated. A static system of social measurement would become less and less useful; to prevent this, we must repeatedly scrutinize our measures and models, and when necessary, adapt them. In the last fifty years, such transformations have occurred in the concept and measurement of employment and unemployment. We will use this case to illustrate the nature of continuing challenges to the statistical measurement of social change.

NEW OCCASIONS NEED NEW CONCEPTS: THE MEASUREMENT OF UNEMPLOYMENT

Throughout much of industrialized history, one of the primary ways of characterizing the economy was by measuring the economically active, employed population. For that purpose, the working force was defined as the total number of gainfully occupied workers in the nation. This concept of the working force, further classified by occupation, was especially useful in providing information on labor resources (Jaffee and Stewart, 1951; Shiskin, 1976).

The explosion of joblessness in the Great Depression substantially changed the usefulness of that information. There was growing recognition that the gainful worker concept did not meet the need for information on short-term changes in the work force for the concept was based on the idea that every individual had a customary or usual occupation or a relatively permanent economic station in life, e.g., housewife, student, or dependent. These statuses were seen as customary and unlikely to change in the short run; hence they required measurement at infrequent intervals. The only people who could be counted as unemployed were those "established workers" who did not have jobs. Excluded from the category of the unemployed were those without employment records or status, such as young people entering the work force for the first time. Moreover, housewives, occasional workers, and those who earned only supplemental income were generally omitted. Not regarded as gainful workers, they were not counted among the unemployed when they could not find work. The numbers of the gainfully employed were subject to attrition through retirement, injury, death, and emigration; they were augmented only through the maturation of young people and immigration (Bancroft, 1979).

The Depression of the 1930s changed substantially the country's needs for information on employment and unemployment. Frequent estimates of unemployment were needed to replace the infrequently collected statistics of the gainfully employed. Also needed were concepts of the work force that would emphasize current activity of the labor market and would furnish the government with information about the number of people who needed jobs. What emerged from the government's desire to respond to the problems of the Great Depression was a different concept of a labor force, one which includes everyone in a population above a given minimum age who is either actually engaged in gainful employment or is looking for work for pay during a specified time period.

Statistics on the gainfully employed focused on the usual occupation or economic role of the individual. The labor force statistics that were established in the 1940s focused instead on the individual's behavior relative to the labor market. There were four classes of labor force participation: working at a job; holding a job, though not working because of temporary layoff or other reason; without a job and looking for work (unemployed); and, finally, not in the labor force. According to this scheme, the labor force is the total of those with jobs and those without jobs who are seeking a job. The unemployed are a separately and somewhat independently measured group. Under the old scheme, an increase in the gainfully occupied implied a decrease in the unemployed. This was not true under the new conceptualization, where the number of both the unemployed and the employed could rise so long as persons were entering the labor force from the "not in the labor force" category. Indeed, the audience in the 1976 Ford-Carter debate heard Governor Carter claim, correctly, that the number of unemployed had risen in the most recent month and President Ford responded, also correctly, that the number of employed had risen. Four years later in the debates between President Carter and Governor Reagan, the same claims could be heard. In both cases, all the information cited was obtained from the Bureau of Labor Statistics; all the contentions were correct as the terms "employed" and "unemployed" are currently defined and measured (Cain, 1979; National Commission on Employment and Unemployment Statistics, 1979: 21–29, 43–56; Webb, 1979).

This process of redefinition in the face of changing conditions and needs is integral to the measurement of social trends. The social sciences, to a far greater extent than the physical sciences, must adapt to new conditions and adopt new, improved, or alternate measures (see Clogg, 1979).

But herein lies one of the most difficult problems to be faced in the study of social change: how can the concepts and measures of a social phenomenon be redefined without also destroying the comparability of measures and disrupting the statistical time series on which so much of the study of social change is based? For example, what current measures of the labor force can be compared with measures of the gainfully employed collected prior to 1940? Or, to return to the previous examples, how could we alter our concepts or measures of the divorce rate or of personal or family income without endangering our ability to understand long-term changes in these social phenomena. In short, how can we reconcile the pressing need for updated measures of current levels of social phenomena with the competing need to maintain continuity with baseline measures?

Although there are no universally accepted solutions to this problem, two strategies promise to provide the basis for discussion and future developments. First, those who support and collect statistical time series must resist changes in conceptualization and measurement that are offered solely for the sake of change, as well as untested small "improvements" in the instruments used to collect information. It is better to continue to use a measure with known measurement error than to replace it with an untried innovation. It is easy to forget that "breaking new ground" in the conceptualization and measurement of social conditions may damage the foundation of the data to assess how those conditions have changed.

When the development of new concepts and measures is imperative, as it is likely to become for many social phenomena, a second set of solutions can be used to reconcile the competing needs for updated and comparable measures.

First, old measures should be overlapped (i.e., continued to be recorded along with new measures) until these new concepts and measures are well understood and their relationship with old measures can be calibrated. In this way, a bridge is built between two series of information measured by different instruments, allowing analysis of a continuous time series that is uninterrupted by changes in measurement.

Second, indicators whose meanings have changed should not be summarily discarded. Adjusting or indexing to a constant meaning is a useful technique to bring current measures in a series in a closer approximation to the metric on which the subject was previously based. Measures of trends in "constant" dollars, for example, attempt to adjust for that portion of an increase attributable to inflation.

Yet another way to meet the needs for replicated and redefined measures is to collect and distribute information in a form that does not solely reconstitute or recode the new data in the series. Numerous private and public surveys and the current Census of Housing and Population, for example, ask a series of questions about the occupation of respondents or of other members of the household. The information provided in response to these questions is usually reported or released in the form of occupational codes. When these codes or classification schemes are changed to reflect changes in jobs and their classification, as in the 1980 Census of Housing and Population, real changes in the condition being measured cannot be disentangled from the artifactual changes produced by changes in classification codes so that they can be joined to previous observations in the series. Providing the verbatim responses to these questions on the data tapes released for public use as well as the new codes would permit recoding of the new information consistent with that for previous surveys or Censuses, thereby preserving the continuity of measurement necessary to assess change in the occupational structure of the United States.

MONITORING ASSUMPTIONS: PROJECTION OF PRISON POPULATIONS

We have already seen that the adequacy of concepts and measures can change along with the conditions they are designed to reflect. Similarly, the validity of the assumptions on which models and forecasts are made can also change. It is therefore as necessary to monitor changes in the variables on which these assumptions rest as it is to record changes in the social conditions and the instruments used to collect that information. We illustrate this point with the case of projections of the prison population. The commitment of government resources to the development of prison facilities must be based, in part, on estimates of the number of people likely to be imprisoned. These projections, in turn, are based on an understanding of how the size of the prison population is affected by the interaction of the criminal justice system and the dynamics of population change.

There are several ways to project the size of our future prison populations. The method used here, to project how prison commitments in Pennsylvania are expected to change between now and the year 2000, is based primarily on calculating the transition probabilities of going from, e.g., arrest to conviction, and conviction to sentencing for specific sociodemographic groups in the population (Blumstein, Cohen, and Miller, 1980). Whether that projection will be correct depends on the validity of the assumptions used.

Figure 3 presents a projection based on this technique. Pennsylvania's prison population can be expected to increase between 1980–1990 and to decline thereafter, as those age cohorts and sociodemographic groups most likely to be imprisoned decline in relative and absolute numbers in the population. The technique rests on the assumptions used to project the future state population and the probabilities of arrest, conviction, and sentencing for various sociodemographic groups in Pennsylvania. These assumptions pertain to change in the levels and rates of birth, death, and migration as well as changes in transition probabilities noted above. (Though not shown here, the probabilities of arrest, conviction, and sentencing by different age, sex, and offense groupings can be disaggregated and used to estimate when specific types of offenders will reach their maximum population in the prisons. Such projections may be extremely useful for planning the future construction of specialized prison facilities.)

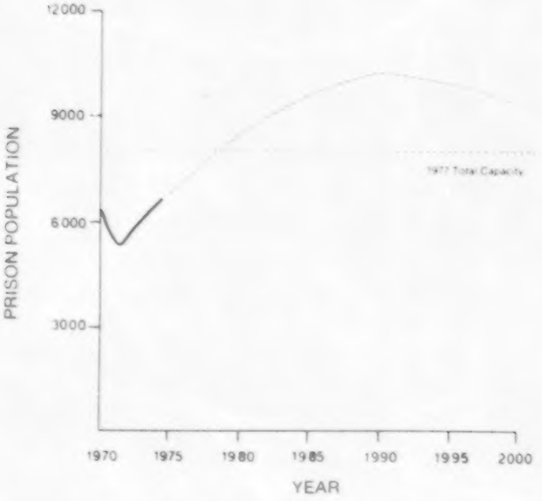

Figure 3. Projected Prison Population in Pennsylvania, 1970–2000.

Source: Blumstein, Cohen, and Miller, 1980:20.

The strength of this technique lies in the fact that short-term population projections are based on knowledge of the size of cohorts already born. The assumptions about changes in the level and rates of births, deaths, and migration are fairly robust, as the rates tend to change slowly and cyclically. The weakness of the technique lies in the assumption of constant or time-invariate transition probabilities.

The implications of this assumption for projections are important. If the criminal justice system remains unchanged (e.g., these transition probabilities remain the same over this period), the prison population of Pennsylvania will decline after 1990. But the probability of many of these events is likely to change. The average sentence length may change substantially, for example, due to new legislation or changes in judicial and administrative policies. Perceptions of the severity of offenses may alter. And changes in the size of prison populations (e.g, are they over-crowded?) may influence judges' decisions whether to sentence convicted offenders to prison.

There are several additional assumptions on which these projections are based. For example, this particular analysis assumes that except for race, sex, and age, similar rates of criminal arrest, conviction, and sentencing can be applied to everyone. Another and more technical assumption is that the probability distributions for both the time served in prison and the number of prison receptions are exponential and that the prison receives inmates at a constant rate during a short period of time. In making these assumptions about the distribution we must also assume that the average time in prison remains at the 1975 level in each offense and sociodemographic group.

The implication to be drawn from the discussion of these assumptions is not simply that forecasts based on transition probabilities (or other forecasting techniques) are inherently difficult, although the many failures in forecasting provide strong evidence for that conclusion (Ascher, 1978). There are several additional implications as well. First, we can learn from forecast failures, but only insofar as we use the future as a test of the implications of the model. And, second, we must continually monitor the indicators that underlie projections. If the average length of sentence changes, for example, an appropriate adjustment in our model will be required. If we discover that we have ignored some important causes of change in the social phenomenon being projected, the model should be revised to incorporate them. Or conversely, by altering the transition probabilities we may see how the future size of the prison population is affected, and then decide how resources can be allocated more efficiently. Continual monitoring of the components of the model and the projection of alternative futures through the statistical manipulation of different assumptions can help us to prepare for, accommodate to, or perhaps even change the future.

Projections of this kind can reduce the range of uncertainty about the future and contribute to the consideration of public policy decisions. Insofar as their assumptions are made explicit, such projections contribute to our understanding of the mechanisms and processes of social change. Continual attention to fundamental variables and the validity of assumptions is a small price to pay for that greater understanding.

In addition to illustrating one of the many tools available for analyzing social change, the prison projection example also indicates the theoretical and practical importance of the size and composition of birth cohorts as they move through the institutions of society. This kind of knowledge contributes to our understanding of the dynamics of change in prison populations and in the status of social institutions such as the social security system; in addition, as Richard Easterlin has argued (1980), it may contribute to our understanding of life chances in such realms as occupation, education, income, marriage, and childbearing. The study of birth cohorts as they age through differing historical periods has yielded an analytic concept that contributes considerably to the statistical analysis of social change.

MODELS FOR THE ANALYSIS OF SOCIAL CHANGE: AGE, PERIOD, AND COHORT EFFECTS

The analysis of age, period, and cohort effects provides a way of understanding how social change occurs. Changes related to an individual's age are called age effects. Changes brought about by external influences and events that occur during the same time period to people of all ages are called period effects. Changes attributable to generational changes are called cohort effects. (A cohort is a group of people who experience the same event at the same time; most frequently, a cohort is used to refer to those individuals who are born during a particular historical time interval.) This mode of analysis attempts to examine specific social trends in terms of these three general components. To illustrate how the analysis of age, period, and cohort effects has helped in understanding changes in diverse social phenomena we offer two distinct examples: changes in attitudes toward racial integration, and changes in the pattern of cigarette smoking.

According to one widely used set of measures of attitudes toward racial integration, the support for integration has risen steadily in the United States since the late 1950s and early 1960s. Approval of white and black students attending the same school rather than separate schools has climbed from 49% in 1956 to 88% in 1980. Opposition among whites to a member of their family inviting a black to dinner has fallen from 50% to 26%; opposition to laws prohibiting interracial marriages has leaped from 37% to 69%; and opposition to whites keeping blacks out of neighborhoods has climbed from 44% to 67% between 1963 and 1980 (Smith, 1980; Davis, 1980, Taylor; Sheatsley, and Greeley, 1978).

What underlies these changes in attitudes? In part, all age groups of the American public have become more supportive of the integration of schools and neighborhoods and an increase in the social relations between whites and blacks. But this general shift explains only a small part of that change, accounting for only about 10% of the total attitude change on racial integration between 1963 and 1978 (Taylor, Sheatsley, and Greeley, 1978:48).

Far more important in explaining the overall change of attitudes toward racial integration is cohort succession. As an older generation dies and younger cohorts mature to adulthood, these newer cohorts come to compose a greater proportion of the general population. To the extent that their attitudes differ from those of their predecessors, there is a change in the mix of attitudes in the population. This succession or replacement of cohorts accounts for nearly one-half (47%) of the total change in racial attitudes between 1963 and 1976 (Taylor, Sheatsley, and Greeley, 1978:48).

The analysis of the cigarette smoking patterns of women in the Unitd States also illustrates the use of cohort, age, and period distinctions in understanding trends. Estimates of the prevalence of current cigarette smoking for successive birth cohorts of women for the year 1900 to 1978 are displayed in Figure 4. Each line in the figure represents the smoking patterns of women born in a specific decade. For example, women born in the decade (1901-1910) smoked considerably more than women prior to the turn of the century. Each successive cohort contained more women who smoked than the previous cohort, until a slight decline set in with the cohort between 1951 and 1960 (United States Surgeon General, 1981:31-34).

These data illustrate the existence of an age effect because the curve for each birth cohort follows the same general pattern—a rise in late adolescence followed by a decline. That is, for each cohort the prevalence of smoking increased with age up to a point and then decreased. Period effects can also be seen. During the 1940s and 1950s, smoking increased for every adult cohort except the oldest; during the most recent period, however, smoking declined for several cohorts. And a cohort effect is also suggested, because the likelihood that a woman smokes appears partly to be a function of

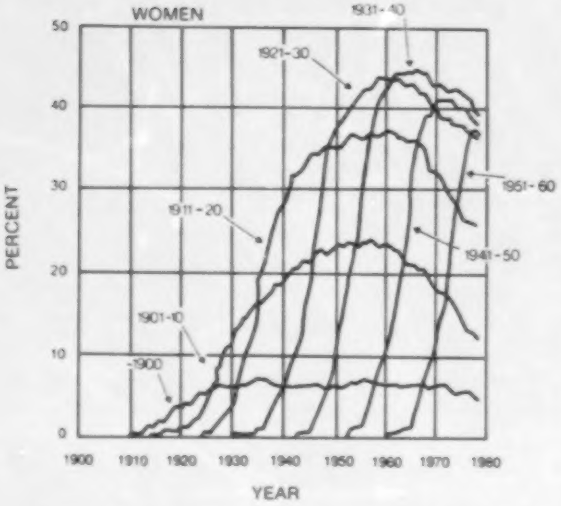

Figure 4. Changes in the Prevalence of Cigarette Smoking among Successive Birth Cohorts of Women, 1900-1978.

Source: Calculated from the results of over 13,000 interviews conducted during the last two quarters of 1978, provided by Division of Health Interview Statistics, U.S. National Center for Health Statistics as reported in U.S. Surgeon General (1981:34).

the year in which she was born. Smaller proportions of women born early in this century consistently have been less likely to smoke than subsequent birth cohorts at similar ages and for each period in this century.

Although it is enlightening to note the existence of each of these three types of effects, social scientists are often more interested in the underlying social processes. For example, the difference in attitude toward racial integration between the young and the old is due in part to the fact that younger cohorts during this period were more highly educated than their elders. Because the educated tend to be more supportive of racial integration than those who are less well educated, the replacement of the elderly population with a generation of highly educated young people increased support for racial integration. But in addition, quite apart from their greater education, younger white cohorts have been exposed to a different set of experiences, which have prepared them to support integrationist positions. Uncovering these experiences is a major objective of researchers who use age, period, and cohort models to understand social change.

It is difficult to develop models that can identify and separate the three effects because any two define the third. For example, given a particular period and specific cohort, age is known and invariant. Given a cohort at a specified age, only one period is possible. Because of this interconnection, one of the three effects is generally ignored in analysis. Recently, however, statistical models have been developed to permit improved accounting for all three types of effects (Mason, Mason, Winsborough, and Poole, 1973; Pullum, 1977; Fienberg and Mason, 1978; Mare, 1980). Using simple but apparently sound assumptions about the operation of age, period, or cohort effects, researchers have applied log linear and logit models to develop distinct estimates of the magnitudes of each effect in specific empirical situations. As these methods are employed more widely, there is reason to hope for advances both in our technical ability to disentangle age, period, and cohort effects, and in our knowledge about how and why social changes have occurred.

Age, period, and cohort effects and transition probabilities are but two of many analytic and statistical tools used to study the causes and consequences of social trends. The techniques are applied to different types of information. Typically, age, period, and cohort analysis has been used to analyze cross-sectional data, i.e., data collected from a sample of subjects during a relatively short period of time. Projections based on transition probabilities rest, in part, on an analysis of panel data, i.e., data based on repeated observations of the same subjects over time. When measurements of social change have accumulated a sufficient number of successive observations, whether panel or cross-sectional, the range of analytic tools for analyzing social change increases. Statistical techniques that can discern the cyclical or periodic components of trends based on series of 100 or more successive observations have been developed and used in the social sciences, e.g., in historical demography and econometrics (Lee, 1975; McClearly and Hay, 1980; Mayer and Arney, 1974). For the somewhat shorter series of observations that are more usually available to social scientists, dynamic regression or structural equation models may be applied (Ostrom, 1978); for a systematic development of a theoretical framework justifying the application of specific classes of these models to social indicator time series, see Land (1979).

Like all statistical methods, these time series techniques rest on numerous assumptions: some concern the presumed causal relationship among aspects of social change; others pertain to the metric by which social conditions are measured; and still others concern the statistical characteristics of the series. Social scientists, in collaboration with statisticians, are developing methods to assess the accuracy of these assumptions; in addition, they are developing techniques that make it possible, statistically, to relax the assumptions or to transform the data in ways that meet those assumptions (Scheffe, 1959; Tukey, 1977; Fienberg, 1977). These methodological developments have been aided by advances in statistics and in computer hardware and programs. Another key step has been the accumulation of time series to which scientists can apply these and other techniques for dissecting social change.

Thus far, we have tried to show how the understanding of social trends is dependent on the concepts, assumptions, and techniques that are used to study and analyze those changes. These, in turn, depend on our choices of what to measure, i.e., the subjects to study. These choices will be the focus of the subsequent section, setting aside equally important issues of determining how well our instruments measure what they are intended to measure.

PRIORITIES FOR MODELS AND MEASUREMENT

The study of social change, like the study of other physical or social phenomena, necessitates choices among those aspects that can be modeled, measured, and analyzed systematically. The first task for public policy and research is to select which aspects of society should be investigated or monitored. In other words, what are the major problems or issues in social change that merit new and continuing attention? In the United States, the major problems and issues in modeling and social change derive from two principal sources: (1) the theories and models about social change that are formulated by social scientists; and (2) attempts to illuminate the problems and evaluate the policies and programs that are important to public or governmental interests.

Many social scientists give high priority to the collection of information about social conditions that contribute to our understanding of how society changes. Models that emphasize the relation of social conditions to change often require the development of new concepts and the collection of new information. Models of the effects of scientific and technological innovation, for example, have generated efforts to measure scientific productivity and have focused the attention of scientists on the social, political, and economic causes and consequences of innovation in science and technology. Similarly, models of occupational mobility between generations have led to the measurement of the status accorded to different occupations in advanced industrial societies.

Models of social change must be tested by empirical observations. Deductions from the models, or projections of change based on them, are tested by the application of analytic techniques to data, many of which are based on repeated observations of social conditions. Where such indicators (i.e., the data) to test these models exist, high priority is given to their continued collection; where they do not, high priority is given to their development. In short, an important criterion for choosing which aspects of social change to study is relevant to the theoretical growth of the social sciences. The development of concepts and ways to measure them, and of methods to test and analyze social change are part and parcel of designing and testing substantive models of social change.

The public and their governments approach the problem of collecting information about society somewhat differently from that of social scientists. Governments gather information pertaining to the choices they must make, and may choose to focus only on matters that can be changed by conscious government action. The most obvious candidates for the development of measures are those elements of society for which governments establish goals and design programs. In the 1960s our society gave increased priority to issues of inequality and discrimination; pertinent measures were developed and used in public policy (United States Commission on Civil Rights, 1978). Currently, the issues of industrial and scientific productivity are perceived as urgent and demand the development of new (and the scrutiny of extant) concepts and measures. To make rational social choices about goals and programs, governments have established programs to monitor conditions such as health, nutrition, housing quality, crime, education, employment, income, and standards of living and have collected information about births, deaths, marriages and numerous other phenomena. Large-scale social experiments (see the chapter by Judith Tanur in this volume) have added to this information. Data collections have illuminated many issues of public and private interest, including political preferences, religious affiliation, consumer confidence and plans, racial attitudes and practices, and the use of goods and services. And national polls on a variety of issues have provided what amounts to a continuing national referendum of important concerns.

Returning to the question that opened this section—which indicators of social change should be given priority of attention and resources?—we find that two answers predominate. One is that those indicators and methods of inquiry that are essential to develop and test the more promising models for understanding social change merit high priority. The other is that those problems and issues that require resolution within the public and its governing structure should have an especially high priority. Considered separately, each answer offers little guidance to resolve their competing claims for limited resources. As a general rule, however, the payoff will be especially high when the interests in explanation and public policy converge (see de Neufville, 1975:239-247). There are at least three substantive areas in which the priorities of government and social scientists for the development of measures of social change are equally high: individual and collective well-being, social inequality, and science and technology.

INDIVIDUAL AND COLLECTIVE WELL-BEING

Social scientists and policy makers wish to model and measure changes in both individual and collective well-being. Considerable progress has been made in measuring changes in the subjective states of individuals—such as their aspirations, perceptions, attitudes, and opinions—and in their objective circumstances as expressed by income, housing, or level of education (Campbell, Converse, and Rodgers, 1976). Less well understood is the relationship between changes in objective and subjective measures of individual well-being and the changes in the well-being of organizational life. We know more about changes in small groups such as households or families than we do about changes in social networks or in formal complex organizations. And we know little about how organizations originate, flourish and die, how their relationships with people or other organizations change, and what the consequences of those changes are for the collective well-being of society.

One of the major public concerns of our time is the capacity of government and our free-enterprise system to meet the aspirations of our citizens. Though there is much agreement that aspirations have made increasing demands on the society's capacity to meet them, we have few if any models that explain the relationship between aspirations and capacity. Nor do we have any viable models of the ways in which organizations, including government, limit individual aspirations so that they do not endanger the collective capacity to satisfy them. What is the relationship among unmet aspirations, mass discontent, and political action? (See Hirschman, 1973 for a novel approach to this subject.) How do societies limit aspirations to avoid chronic conditions of anomie?

A second major public issue is the quality of life—both of individuals and collectivities. We need to understand better, for example, whether changes in so-called "objective" conditions of life make people happier, more content, or satisfied with their lot. Research suggests that we cannot assume that changes in objective living conditions will produce changes in subjective evaluations of well-being (Campbell, Converse, and Rodgers, 1976; Easterlin, 1979; Quinn and Staines).

Although our understanding of changes in individual well-being and the relationship between individual aspirations and collective capacities to satisfy those aspirations may be described as meager, our understanding of changes in collective states of society is even more limited. We need to understand, for example, not only how crime affects the lives of individuals but also what its consequences are for neighborhoods, communities, and the different organizations within them. Concepts such as justice or social cohesion are not reducible to the lives of a society's individual members nor can they be measured simply as the sum of observations on individuals. An increase in divorce, to cite an example that demonstrates individual and collective properties, is both a change in the status of individuals and a change in the social relationships and organizational structure in society. Each divorce increases the number of single-person households and decreases the number of two- or more person households and families. It changes the relationship of husband to wife, of children to parents, of insurers to insured, as well as the taxable income and legal status of all parties.

At present, the significance of changes in the collective states of society is poorly conceived, measured, and reported. Yet these concepts represent some of the most important elements one wants to know about societies and how they change. We know little about the demography of organizations, the conditions under which they flourish or die, the changes in their relationship to each other, and the size and composition of their membership. We have yet to obtain comprehensive information about the female and minority composition of organizations and are therefore unable to calculate changes in the rates of compliance with laws intended to eliminate discrimination. Nor are we able to assess changes in the rates at which the hiring practices of organizations are changing—a statistic for which aggregated information on individual employment is not suitable. Surely, it would be unwise to abandon attention to measuring changes in individual states and their consequences for collective well-being. But models and measures of collective states of society, based on the behavior of organizations as well as that of individuals, are at least equally important.

In short, well-being is a complex social phenomenon that eludes simple classification and measurement. It is a property inherent in individuals and in the collective life of society; and it requires measurement of subjective and objective conditions. Clearly this is a research area in which a great deal of work needs to be done. Quality of life will be measured better when we know more about what makes people satisfied with their lives and their living conditions; that better understanding, in turn, will improve our measures of the quality of life for individuals. But we must also understand how collective well-being depends upon the quality of organizational life.

SOCIAL INEQUALITY

Social inequality is a major theoretical issue in the social sciences. Such matters as the redistribution of income, and the individual and collective consequences of a system of rewards and opportunities based on criteria of achievement or ascription, are studied from the perspectives of many disciplines. Political scientists are concerned with the consequences of inequality in political participation for democratic authority. Psychologists model the subjective consequences of inequality. Economists include it in models of the aggregate economic performance of nations. Each of these areas has made headway in developing indicators that permit some measure of changes in inequality. Yet in each there is a pressing need to develop more sensitive, refined, and accurate indicators of changes in education that go beyond measures of the number of years of school attended; of changes in wealth that include more than measures of earnings; and of changes in the equity of treatment before the law that include more than the rates of conviction, sentencing, and parole for different racial or socioeconomic groups in society.

More progress has been made in describing inequality than in understanding how it changes, however. Social scientists need models as well as measures of social inequality to explicate its causes and consequences. It is reasonable to expect that policy needs for measures in this area will continue. Courts can be expected to continue to use indicators of equality of treatment before the law. Legislative and administrative officials will continue to rely upon measures of social inequality to determine how resources shall be allocated among competing social programs. And both scientists and administrators share an interest in whether planned social changes or social programs will have intended or unintended effects on the distribution of resources in our society.

INDICATORS OF SCIENCE AND TECHNOLOGY

Explanations of social change may incorporate any number of factors, and it is now generally agreed that science and technology deserve a prominent place in these models. We need to know how developments in science and technology may lead to changes in economic growth or fertility rates, and, reciprocally, how changes in public policy affect science and technology. But despite the importance of these areas in understanding social trends, relatively little effort has been devoted to the statistical measurement and explanation of the ways in which science and technology cause and are affected by social change. There is, for example, a paucity of causal models to explain how different kinds of science and technology affect rates of economic growth. Nor is much known about the economic effects of the technologies associated with research and development in the social sciences: management training, programmed language instruction, educational testing and career counseling, economic forecasting, and computer software all owe much to social science research but their effect on the economy and society is not well understood.

Central to an increased understanding of the role of science and technology in social change is the development of measures for use in models of social change or in the allocation of resources. Four general types of science and technology indicators are needed: (1) those designed to establish and evaluate science and technology policy; (2) those that describe the public's understanding of and support for science and technology, both as policy and as a technique for understanding the social, physical, and biological world; (3) those that permit us to understand the social organization of science and technology; and (4) those that explore the impact of science and technology on society.

Science and Technology Indicators for Public Policy

The most well-developed set of science and technology indicators are those relating to the development of science policy. Their importance was emphasized in a January 1981 article in *Science* by Dr. Frank Press, who referred to science indicators as one of the major sources of information used in making judgments about science policy (Press, 1981). Dr. Press specifically mentioned the importance of the National Science Board's *Science Indicators* volumes, which provide extensive information about the level of research support and the current conditions of science and technology in the United States (National Science Board, 1973, 1975, 1977, 1979).

The *Science Indicators* volumes are important for several reasons. First, they provide a continuing record of trends in the social organization of science and its resource base; this information is essential for developing and assessing science policy. Second, they contain indicators that can be used for the various objectives of government, industry, the academy, and the media. Each volume reports trends in the allocation of resources across scientific disciplines and research sectors, changes in the public and private management of research and development, and measures of the current and prospective status of scientific and technical personnel and training. The volumes also include indicators used for international comparisons of the growth and consequences of science and technology, such as measures of the balance of payments, patents registered, and investments in various types of R&D.

Third, the *Science Indicators* volumes focus attention on the production, analysis, and use of information about science and technology, and their preparation stimulates collaborative efforts to develop appropriate information. The National Science Foundation staff who produce the report have cooperated with those who use and analyze the indicators and these joint efforts have enhanced the caliber of the information collected and reported in these volumes. After criticism of an early volume for its data used on public attitudes toward science, for example, the National Science Board commissioned a major review of the subject; this led to a considerably expanded data collection effort that drew from models of the way in which public opinion is articulated in the United States. The information on public attitudes toward science that is drawn from this new survey will be published in *Science Indicators 1980*. The collaboration between the Foundation, the academy, and other government agencies has also been reflected in regular review symposia and publication on the *Science Indicators* volumes sponsored by the Social Science Research Council's Subcommittee on Science and Technology Indicators (Elkana et al., 1978; Zuckerman and Miller, 1980). (See *Knowledge*, vol. 1 (4), for a discussion of other science indicators research activities.)

The usefulness of the work in the United States in science indicators for public policy has contributed to a growing international interest in indicators of science and technology. The Organization for Economic Cooperation and Development (OECD) recently concluded the third of a series of workshops and conferences for representatives of member countries on science and technology indicators. Present plans call for the organization to produce a biennial report on science and technology indicators (*Science Resources Newsletter*, 1980).

Despite the attention to and research in the development of this area, there are still major measurement problems. The focus of research—and consequently also of the *Science Indicators* volumes—is concentrated more on indicators of science than on measures of technology. There are very few measures of the knowledge and innovations yielded by science and technology. Indicators of funds and personnel for R&D in science and technology are considerably better developed than indicators of the products or outputs of R&D activities. To improve our understanding of the status and prospects of science and technology, measures of inputs *and* outputs are needed. There is also a need to disaggregate indicators into specific sciences, scientific specialties, and topics of study. For example, civilian expenditures for technological R&D should be separated from expenditures for defense; this would help not only to target government programs but to understand processes of scientific and technological change.

Public Understanding and Support for Science

To limit science and technology indicators to such measures as manpower, expenditures, or the number of registered patents would unduly restrict our understanding of the role played by science and technology in affecting social change. It would also limit our understanding of why science and technology policy changes as it does. Science operates within a public framework. Public understanding of science—its interest in and support for scientific work—is essential to the growth and development of the enterprise. Knowledge of changes in this public framework provides a base for developing and evaluating policies on scientific research and education; it also provides a foundation for understanding the changing relationship between the public and the scientific community (*Daedulus*, 1978).

Again, there has been some progress in the development of concepts and measures concerning this aspect of society and technology. Indicators of public understanding of science may be found in a number of sources, including the *Science Education Data Book* produced by the National Science Foundation, and trends in students' science scores provided by the National Assessment of Educational Progress (National Science Foundation, 1980a). Public interest in science and technology is monitored in part through sales of books and magazines on science and technology, the share of television audience for shows on science and technology, and attendance at science and technology museums (United States Department of Commerce, 1976, 1980). Public support for science is measured by surveys assessing public confidence in science and scientists, attitudes toward R&D expenditures, and attitudes toward the ability of scientists and engineers and their methods to find solutions to pressing problems (Miller, Prewitt, and Pearson, 1980).

The relations of science and its public are revealed as well in the changing patterns of careers chosen by the nation's youth and in the way the electorate supports or opposes candidates for public office or votes in referenda on policies related to science and technology. Other aspects of this changing relationship are revealed in attitudes and behavior expressed through public protests and support of organizations that emerge in response to developments in science and technology.

The recent survey of public attitudes toward science and technology commissioned by the National Science Board has helped to clarify some of these issues (Miller, Prewitt, and Pearson, 1980). But we have not had enough baseline measures to replicate over time; only when these are available and repeatedly asked will we be able to determine whether and why many of these aspects of the public's understanding and support for science are changing.

Social Organization of Science and Technological Development

A third area of science and technology indicators research concerns how science and technology are organized to acquire new knowledge and produce new applications. The policy focus of indicators of input and output ignores the process through which inputs become outputs. Moreover, we do not now know how to measure changes in the most elusive product of scientific research, new ideas.

Additional indicators of internal processes of science are needed to monitor productivity in R&D and creativity in particular laboratories or disciplines. Indicators of the tie between research support and the application of science to social ends, ranging from industrial production to a more healthy people, would be valuable both from the perspective of science policy and for measuring internal processes in science itself.

Impact of Science and Technology on Society

This is the broadest and most complex area for the development of science indicators. It is also one of the oldest. As early as the 1920s, William F. Ogburn, recognizing the importance of science and technology in social change urged social scientists to monitor trends in science and technology in order to understand the social and economic changes taking place in society (President's Research Committee, 1933). In the 1960s, Raymond Bauer and his colleagues attempted to determine the effects of the space program on American society, but concluded that the effects could not be measured until there were improvements in both data and social measurement (Bauer, 1966).

The problems faced by Ogburn and Bauer were considerable. The direct effects of scientific or technological changes, while often considerable, frequently take place over a long period of time and do not remain static over time. This makes it difficult to develop measures of the interaction of scientific and social change for any single period. It also means that useful comparisons over time cannot be made until enough time has elapsed to permit consideration of all the changes. The indirect effects of scientific and technological changes are even more difficult to identify and measure, particularly because they interact with other causes of change.

The future study of indicators of the impacts of science and technology on the society should examine the kinds of interactions that occur and the ways in which they influence change. Emphasis should be given to social as well as technological innovations. Social and behavioral research has shown that the quality and efficiency of industrial productivity can be improved not only through technological innovations but also through social innovations in management and production (Cole, 1980). Indicators of these social innovations would be valuable for both the study of social change and for industrial policy.

Volume II of the first *Five-Year Outlook* pointed out that a principal effect of technological development during recent decades has been the accelerating rate of human alterations of land, vegetation, water, and air; there was relatively little documentation, however, of the nature, extent, or rate of acceleration, nor of the ways that humans were causing these changes. Rather, attention focused on ". . . the nature, extent, and seriousness of the problems posed by toxic chemicals," and the hope expressed that ". . . as more knowledge is gained, we will learn how to better control and reduce toxic chemical hazards" (National Science Foundation, 1980b:249, 261). The control of toxic hazards is as much a matter of understanding social causation and monitoring the effects of social programs as it is of understanding the chemical nature of these substances and their consequences for human health. Knowing that toxic chemicals may cause cancer or that chemical treatments can reduce toxicity is no assurance that their production and distribution can be controlled effectively. These latter issues require an understanding of how social change can be brought about.

Measures of social change must be developed to parallel the increased knowledge of how to design more efficient and selective technological controls. To develop new technology for sequestering, degrading, containing, or removing chemically laden wastes is not enough. It is equally important to develop ways of monitoring the efficacy of such control systems; this will require models of regulatory systems and how they work, so that we may deal with their failures.

PROBLEMS IN THE DEVELOPMENT OF A NATIONAL SYSTEM OF SOCIAL MEASUREMENT

The statistical measurement and analysis of social change depend heavily on public policies and the manner in which the research enterprise is organized. Public policy on the measurement of social change affects the substance of inquiries—what the society wants to know—and the development and selection of procedures to answer those questions. How we gather information and conduct analyses raises questions about statistical policy; the relative emphasis to be placed on short-term and long-term research; the locus of responsibility for gathering and reporting information; the ownership of data gathered for scientific inquiry; the means of producing the data, and many other issues. Some of the major issues in statistical policy are noted below, together with a discussion of a few of the conditions that affect how well the statistical measurement and analysis of social change is currently conducted in the United States.

CONTROL OF STATISTICS PRODUCTION

Because Federal government agencies report information on national trends and provide information on state and local governments, it might seem that the Federal government is responsible for collecting the data as well as for compilating and reporting them. Yet that is often far from the case. Much information that is collected and reported by federal agencies derives from reporting systems over which the Federal government has little if any direct control, and over which it can exercise relatively little quality control by audit or direct intervention. The Federal statistical system is a mosaic of public and private information systems; most information relevant to state, local, and private interests is collected by institutions outside the Federal government's direct control. Vital statistics on births and deaths depend upon reports of local coroners, physicians, and other officials who report to county registrars, who then report to state and Federal statistics officials. Even where a single system appears to exercise control over the production of information, as in Federal prosecutorial or court statistics, control is impaired by the institutionalization of discretion in district offices. Dual bookkeeping or dual statistical operating systems for local and Federal reporting purposes exist. In highly complex information systems, such as those of the Environmental Protection Agency, a mix of state and Federal reporting systems is the basis for agency statistics and a potential source of variation in the way in which information is collected and reported.

Variation in statistical reporting by local collection units can affect the quality and quantity of information on which social trends are based. A local police department may fail to report or the FBI Uniform Crime Reporting system may temporarily suspend the inclusion of information from some local police departments because of unexplainable fluctuations in the information supplied. Such lack of completeness in a reporting system poses the problem of how to take "missing information" into account in reporting totals. The problem is even only more compelling where information is produced by private organizations, for example, the information on school busing, which is obtained from public and private schools. Information on industrial accidents or compliance with standards for regulating the production of nuclear power depends on reports from private organizations. If one wants to know how often nuclear power plants violated NRC standards within a given period, one must depend on a mix of private and public data collection and reporting.

The quality of information on social change may also be affected by the division of labor which locates much (though not all) social research in the universities, and statistical data gathering and its archiving in the government. This arrangement presents a number of difficulties for the coordination of research and development in the measurement of social change.

THE OWNERSHIP OF INFORMATION

Proprietorship of information exists when the agency collecting the data has the right to limit the access of others to it. This kind of ownership seriously impairs the development and dissemination of quality statistics on social change, for it means that access to information is limited, and that documentation and opportunities to scrutinize the production of information in order to assess its quality are restricted.

Public access to governmentally produced information has increased under the Freedom of Information Act and so-called state and local "Sunshine" statutes. But much information in effect remains proprietary because it is in a raw or unprocessed form, poorly documented, and not uniformly accessible. Transforming raw data into a set of social indicators for diverse public and private purposes is no simple task. Although data may be released from which confidential information has been excised, only a limited number of people can use data in this form. Those who can process this information are often hindered by deficient documentation concerning data collection and processing. And to learn of its availability and acquire the information when it is developed by an agency solely for internal use is likewise difficult.

There is no simple resolution to such problems. But a priority for any Federal, state, or local information system must be to determine what is to be routinely processed and reported. We need scholarly as well as managerial attention to decide what information about social change should be accessible and reported routinely, and what information about the data and processing will facilitate access and analysis.

Closely related to the problem of accessibility and proprietary interests is the lack of sufficient opportunity to assess and affect the quality of information. Much work needs to be done on statistical means for assessing data quality, on how to control for and take account of errors in its production, and how to bring about institutional arrangements that lead to high quality information for public use. To resolve these problems, attention must range beyond the Federal statistical system upon a national statistical system, in which the intimate connections between public and private information systems are recognized as both a strength to be used and a problem to be solved.

NATIONAL OR LOCAL RESPONSIBILITY FOR INFORMATION

The word "statistics" originated with the rise of state accounting and accountability. Statistics were developed to assess the state of the state, to describe its past, and to hold it accountable in the future. The history of state accounting reflects the development of a vast array of statistics focusing on what governments do and upon how they collect and disburse revenues.

Because of the tradition of independence among governing units in the United States, each one has tended to develop its own statistical accounting system. As a result, there is considerable difficulty in comparing governing units or in merging information from them. For example, despite several attempts during the past decades to match and merge state court statistics, we are still a long way from having comparable statistics; due more to differences in statistical information systems than to differences in the law and its administration. Statistical indicators are most useful when comparisons can be made among them. Demands for comparison arise not only because larger jurisdictions must hold their smaller subunits accountable for funds, but also because each level of government seeks to guide its course by comparison with others. The decision about how much a municipality should spend for fire protection will depend in part upon how much is spent in comparable jurisdictions. Note that in order to make this comparison, both the jurisdictions and the information about them must be comparable.

Each level of government must attend to these issues in some degree. Yet it appears to have fallen largely to the federal government to initiate systems of data collection that facilitate comparison among units and provide for the merging of information from smaller into larger ones as well as its disaggregation from larger into smaller ones. From the perspective of organizing statistics, central coordination and control of the collection and collation of information appears to be an effective way to insure that information and their bases are comparable insofar as this centralization is accompanied by the standardization of concepts and measures and attention to issues of data quality.

Federal leadership and sponsorship is not without its costs, however. A principal one is that federal needs and priorities for information come to take precedence over state and local ones. Moreover, proprietary rights in information tend to be assumed by centralized bureaucracies, to the neglect of equally compelling claims of decentralized operating units and more local bureaucracies.

A major consequence of granting priority to Federal statistics is that the description of social trends at the national level tends to focus perceptions on problems and their resolution as national ones; such a description underplays the fact that these problems arise, and often can be resolved, in local areas by local authorities. Decentralized governing structures can be undermined and their options restricted if they lack the information necessary to assess local variations and problems. Even where local governments develop such information, they are often severely hampered in acquiring information about comparable units that would assist in their definition and resolution.

A major goal for social scientists must be the development of statistical measures of social change that meet local and state as well as federal needs and priorities. That development requires statistical as well as political attention, and neither is simple to obtain or sustain. Collecting and collating information is costly. Moreover, any agency that collects information will ordinarily attend to insuring the quality of data it finds immediately useful rather than to its utility for future comparisons that are not germane to day-to-day management.

How can we develop concepts and measures of social change that meet requirements at all levels of government and maintain high quality data at relatively low cost? Several statistical courses offer promise. Synthetic estimates for smaller areas are being developed that make use of local population counts in conjunction with relationships observed in data obtained on a national level. Another promising strategy is the increased use of sample surveys to create state and local as well as national indicators, thus supplementing national sampling frames so as to allow inferences about these smaller units.

EMPHASIS ON SHORT-TERM LONG-TERM RESEARCH

One of the critical obstacles to the development of a national system of statistical indicators—integrating Federal, state, and local government interests with private sector interests in understanding social trends—arises from the way in which research on social change is funded. Current Federal support of research rests on budgetary cycles and policies that are more likely to restrict research support to short-term rather than long-term funding. The same is true of the funding of systems for the collection, storage, and retrieval of data. Historically, the development of measures of voter preference, consumer confidence in the economy, and crime victimization statistics, for example, have depended on funding of such short-term that the assurance of statistical time series has been precarious at best. Although one- and two-year grants for research provide incentives to demonstrate immediate pay-offs in order to insure continued support, this system of funding is often at odds with the development of measures of social change that require lengthy series of comparably measured observations.

The intimate connections between research and development require long- as well as short-term funding, particularly for the study of social change where the concepts and measures are more meaningful in the long-term than in the short-term. The need to arrange continuous funding on a project-to-project basis is a serious drain on the time and energy required for developing information about social conditions and for measuring, explaining, and projecting the course of change.

VERIFICATION OF THE ACCURACY OF INDICATORS

A societal need for information creates the need to invest in information systems and evaluate their performance. Hence data development itself requires research on how to gather information with known, if not controllable, error properties, to insure that changes in the indicators can be regarded as measures of change in the society. Verifying the accuracy of measures of social change is costly, however. When resources are fixed, the allocation of research funds for this purpose will channel support away from efforts to collect, analyze, and report that information. In one extensive effort to verify the responses of subjects regarding health service delivery, verification efforts used one-third of the resources, extended the completion of the project by 18 months, and complicated data processing and analysis (Andersen et al., 1979:122–131). In the coming years, choices concerning this investment will be made more explicitly as cumulative research experience provides more information about the subjects and conditions under which the accuracy of indicators must be verified.

A FIVE-YEAR OUTLOOK FOR RESEARCH ON SOCIAL CHANGE

Research on social change will inevitably have short-term as well as long-term goals and will serve needs for both basic and applied information. One problem for research and development programs in this area is how the share of prospective resources should be allocated among these needs and goals. Who is to decide what is to be studied, for what purpose, and by whom? And by what institutional arrangements is the task of monitoring social change best accomplished? We will conclude by briefly recapitulating those aspects of the study of social change that will require special attention in the coming five years. The first of these pertains to the objects of that research.

Much of the research on the effects of social change focuses on its consequences for the welfare of individuals. Our major models of collective welfare are based on optimizing or maximizing that welfare. Yet there is more to collective life than the sum of its members. Collective welfare depends also upon social institutions and organizations. Just how changes in social institutions and organizations affect collective welfare is not well understood, and basic research in this area is essential. Of immediate importance is the development of social indicators of institutions, social relationships, and organizations. This research must address such questions as how the bureaucratization of service delivery systems affect not only individual recipients but also the collective capacity to deliver the services; and how changes in education, rewards, and legal institutions affect social inequality.

Causal modeling is another aspect of the study of social change that requires attention. The past decades have seen a growing accumulation of measures of social and economic conditions of individuals and an increasing sophistication in measures, for example, of health, housing, and public safety. Less effort has been devoted to understanding the causes of these changes and their implications for public policies. Nowhere is this more apparent than in the area of the role of science and technology in social change, where we need to develop better causal models of the ways that science and technology affect economic and social growth.

Inattention to the role of science and technology is apparent also in the realm of science policy. Few models exist that are relevant to setting science policy, and relatively few reliable indicators are available to assist in shaping or assessing its impact. In science policy, the indicators themselves need development. Typically they provide information about scientific manpower or budgets for scientific research and technological development. What we lack are indicators for assessing the effects of these inputs; we have few good measures, for example, of the generation of knowledge and the production of innovations.

Research and development in the study of social change cannot be advanced without a concern for institutional facilities and resources. To an increasing extent, social science requires the commitment of "big science" resources. This development raises fundamental issues about resource allocation and how research institutions and investigators are to share data collection and analysis.

The growing costs of survey research and, more generally, of the collection, processing, and maintenance of all statistical data require a reexamination of the individual science model on which many research programs are based. Large data collection programs must grapple with the problems of providing access to a wide community of scholars while at the same time attending to the needs for continuity of measurement and theory-based research. We must give a priority in the next five years to research on increasing the inferential power and cost efficiency of surveys and to the development of alternative measures of social trends that provide comparable accuracy for fewer or equal resource commitments. We must also study the organization of research itself and attend to the unique problems posed by big science.

It is tempting to conclude this overview of one aspect of research in the social sciences with petitions for changes in the ways that we study social trends. The preceding paragraphs reflect the belief that some aspects of this research are still in their infancy. Moreover, the exploration of new issues and the illumination of old ones in new ways are attractive inducements, both to the scientist and to those who support that research. Continuing established programs, replicating previous studies, or contributing to the accumulation of existing measures of social conditions may be inherently less appealing than breaking new ground. We will conclude, however, with a call for these latter research strategies. Only through the accumulation of repeated observations produced by a strategy of continuing measurement, can the extended process of change be studied. Many existing measurement programs represent considerable investment in the development of concepts and measures and our understanding of social processes. They should not be discarded hastily in the pursuit to change the way in which we study social trends.

NOTE

1. This chapter is in an important sense a group rather than an individual product, based on contributions from the entire professional staff of the Social Science Research Council's Center for Coordination of Research on Social Indicators. Among these, Robert Pearson played the central role, working with materials furnished by himself and by Donald J. Hernandez, Nancy McManus, Roberta Balstad Miller, David E. Myers, Robert Parke, and Richard C. Rockwell. James Davis, William E. Mason, and Kenneth Prewitt reviewed the chapter and provided suggestions. Karen Crouse and Celia S. Futrovsky took care of the typing. I am indebted to all the above, especially Robert Pearson, and also, for many stimulating discussions of social measurement, to the present and former members of SSRC's Advisory and Planning Committee on Social Indicators.

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6 Social and Emotional Development in Children

Martin L. Hoffman

SUMMARY

America has always shown a deep concern for its children and their education. Parents, schools, and family assistance agencies have all benefited from knowledge derived from research on the way children develop. In the past, most research on growing up has emphasized children's cognitive or intellectual growth, but in recent years, an increasing amount of research has focused on children's social and emotional development. This research focuses on questions of how children acquire self-confidence, the motivation to help others, a knowledge of society's complex laws, rules, and norms, the ability to comprehend and empathize with the plight of others different from themselves, and the capacity to control destructive or anti-social urges.

Recent research offers preliminary insights into some of these complex issues and suggests likely directions for future research. Researchers studying infants have begun to document the importance of early mother-infant interaction. Close, frequent, affectionate, and responsive contact with a primary caregiver in the first year of life appears to lead to the development of an infant who is securely attached, a characteristic which contributes to the child's later psychological adjustment. Other studies have shown that infants in the first year show facial expressions of all the basic emotions and that even at this young age the mother and infant develop subtle nonverbal patterns of communications which form the basis for more complex social interactions and relationships later. The child's comprehension of others appears to progress through four distinct stages, from an initial confusion between others and the self to an eventual awareness of others as having identities beyond the immediate situation. Research suggests that this development, called "social cognition," forms the basis for children's conceptions of morality and for the definition of distinct stages in the emergence of helping and other "prosocial" behaviors.

Research has also focused on the impact of parents, other children, and television on children. The majority of studies on the impact of an employed mother on children's social and emotional development show little or no negative effects and in some instances have shown some benefits. Similarly, most research on the impact of divorce has found only minimal long-term negative effects on the children. However, this research is limited in scope. Parents' use of inductive discipline techniques (in which the negative consequences of an act are explained) and their frequent expression of affection outside a specific discipline encounter, appear to foster the internalization of morality. Peer interaction that is su-

pervised by adults can be a useful way to teach children how to relate to others and solve problems, but there is little evidence that unsupervised children can control aggressive behavior or adopt socially accepted behavior. Most research concerning television's effects on children has focused on the relationship between violent programs and aggression. While laboratory experiments have shown that television can encourage violence in the short run, the evidence for long-term effects is not conclusive. Other studies suggest that television can encourage cooperative and prosocial behaviors in children, but it is most likely to do so where supplementary activities or training occur.

Research on motivation suggests that empathy, or the ability to perceive, understand, and vicariously experience the emotions of others, plays a central role in the child's emerging capacity to help others or act in other socially beneficial ways. Studies have shown that attaching external awards to children's activities may actually decrease their interest in these behaviors.

Research on social and emotional development in children is directly related to public policy concerns and institutional practice. Studies on the importance of early mother-infant interaction, for example, have helped shape hospitals' arrangements for infant care immediately following delivery and have influenced the speed with which adoption agencies place young infants. Emerging findings on how divorce and maternal employment influence the development of young children promise to contribute to various child care policies and practices. While character development has always been a controversial function in American education, an increased understanding of those conditions conducive to prosocial behavior and moral internalization must be considered valuable information for teachers and parents alike. Clearly, there is also much basic research on social and emotional development that has little immediate use in public contexts, yet the mental health and social vitality of children, as well as their intellectual competencies, are of major concern to many government and private agencies, and their ability to function effectively depends upon a sound knowledge of how children develop.

INTRODUCTION[1]

In the late 1950s, stimulated by the innovative work of Piaget and by national concern about the need for scientific talent, the attention of developmental psychologists was preempted by studies of cognition. The resulting growth in cognitive research was later reinforced by the "War on Poverty" and the inauguration of project Head Start. In recent years, an increasing number of developmental researchers have focused on social and emotional development, again inspired as much by social issues as purely scientific concerns. It is probably no coincidence that the student activism of the 1960s, the rising crime rate, and heavily publicized reports of corruption have paralleled the sharp rise of research on the internalization of moral norms and the emergence of areas of study such as empathy, role-taking and altruism. Similarly, the women's movement has contributed to the burgeoning of research on sex-role development.

The study of social and emotional development in children involves many complex and elusive issues. How do children acquire the values, social skills and motivations that prepare them for a satisfying and productive adult life? How do they come to understand beliefs held by others that may differ from their own and to empathize with others' feelings of distress or sorrow? How are destructive or anti-social tendencies restrained? In pursuit of answers to questions such as these, researchers have employed a great diversity of theories and methods. Although the field is still young it is possible to identify the most influential theoretical approaches and the major methodological paradigms. Clearly, Freud, George Herbert Mead, and Piaget are among those scholars whose conceptions of development have informed generations of researchers.

To Freud, a child's early interactions with parents set in motion psychological dynamics that influence social relationships and motivations for the entire life course. These processes, as elaborated by Freud, may involve an intense identification with the parents and incorporate powerful sexual and aggressive drives; or as suggested by more contemporary social psychologists, the processes may consist primarily of modeling and imitation. Regardless of the specific processes involved, the legacy of Freud continues to influence developmental research and is reflected in various attempts to understand parental influences on social and emotional development.

The sociologist George Herbert Mead espoused an interactionist view of development that emphasized the importance of the child's gradual involvement in an increasingly complex network of social relationships—from early parental authority to later work roles and intimate friendships. In addition, he argued that the child contributes to the emerging social reality: that the socializing effects of parents, peers, and teachers are influenced by the child's own individual characteristics.

Yet the theoretical perspective that has perhaps most influenced research on social and emotional development has been that of Jean Piaget. Building upon careful observations of children's early behavior, Piaget elaborated a developmental sequence of cognitive and accompanying social skills, tracing the child's progression from a naive egocentric orientation to a sociocentric perspective that provides the child with an understanding of the views held by others. Although Piaget constructed his conceptions of development around transitions in children's reasoning processes, they had profound, often explicit, implications for research on social and moral development.

While themes from each of these theoretical frameworks can be discerned in the research reported here, no single theory has generated an extensive program of empirical research, and few studies have spanned many stages of development. In the early years of this field, most researchers have chosen, instead, to examine highly specific issues, employing more modest middle range theories to study children within a fairly limited age range. The coherence and broad patterning of developmental findings that one might hope for has yet to emerge.

Just as no one theoretical perspective has generated extensive systematic research on social and emotional development, no single methodological paradigm has predominated; and techniques for conducting research on children have been changing. Correlational analysis was one of the earliest approaches employed and remains a valuable technique to obtain clues about early development. Researchers measure a variety of social and affective characteristics for a large sample of children and simultaneously assess a number of variables presumed to relate to these traits, such as social class or parental disciplinary techniques. However, the correlations obtained in such studies are suggestive only and cannot demonstrate causal connections; as a result a number of other research strategies have emerged.

Cross-sectional studies, extensions of the correlational approach, examine characteristics of children of different ages and can provide insights into age related changes. This approach confounds the effects of age and cohort (year of birth), but the same cross-sectional studies administered repeatedly to representative groups of children can, over time, provide more valid developmental information, allowing for control of cohort effects and offering some assessment of the impact of historical events. In fact, the systematic collection of national data on children and families has been proposed as part of a new effort to develop national childhood indicators, similar to efforts that collect social indicators of employment and health for adults. Comparable data on the social and emotional life of the nation's children would establish important baseline information for assessing the impact of various social programs or unanticipated historical events.

Longitudinal studies, which follow the same children for an extended period of time, allow researchers to trace the impact of early life experience on later social and emotional development. Such studies have been rich sources of information about the specific groups studied but generalizations to other cohorts must be made cautiously. While multiple cohort longitudinal studies are possible, like all longitudinal research, they are costly.

Laboratory studies, in which variables are manipulated and outcomes observed, have been the customary way for developmental researchers to investigate causal connections. A large proportion of the research on social and emotional development has been conducted by observing children and sometimes parents from behind the one-way glass of university laboratories. Yet even with the strengths of experimental design one must question whether the events and outcomes observed here would occur outside the laboratory as well.

Developmental researchers are turning increasingly to the insights provided by systematic field observations. This shift in methodology is partially a result of the availability of compact audio and video recorders, but it is also a response to a growing desire to document social interactions and emotional expressions in a variety of natural settings. Researchers are employing innovative strategies to study development in field situations; using electronic beepers to generate self reports (Czikszentmihalyi, 1977) and studying children's emotions through tape recorded observations by the mother in the home (Zahn-Wexler, et al., 1979). By systematically noting the contexts in which certain behaviors recur, and at times experimentally modifying the contexts, it is often possible to identify the causes of naturally occurring behaviors. For these reasons, it is likely that systematic observing and intervention in natural settings will become a preferred method by a growing number of researchers. As the research reported here illustrates, however, a truly comprehensive knowledge of social and emotional development will require insights from the full range of methods available.

Knowledge concerning social and emotional development bears a particularly sensitive relationship to public policy. To understand how children acquire and become committed to values and constructive social behaviors does not mean that social interventions can be designed to promulgate the most desirable traits. Unlike cognitive performance, where consensus on desirable outcomes usually can be reached, social and affective competence resists such easy determinations. Even if consensus could be attained, it is not at all clear where responsibility for the development of these competencies lies. While the learning of cognitive skills is readily relegated to the schools, the encouragement of social and emotional growth in our society generally has been considered to be the primary concern of family, church, and friends. These are arenas of influence in which governments justifiably hesitate to intervene. Nonetheless, knowledge concerning the processes of social and emotional development can be used directly by these socializing agents. Federal, State, and local governments would be remiss if they did not encourage the growth and dissemination of developmental knowledge and apply it whenever it is relevant to their natural involvements with children. In a society that has so recently experienced ethical and moral dilemmas of major proportion and witnessed unprecedentedly high rates of violence, crime, and delinquency, the encouragement of a more adequate understanding of children's social and emotional development must be viewed as a most valuable research enterprise.

The research reviewed here suggests that important advances are expanding the boundaries of our current knowledge. This chapter will summarize some of the major themes of recent research, mainly on the period from infancy to adolescence; it will report known facts and informed hypotheses, identify important gaps in our knowledge, and indicate some of the directions research may be expected to take in the near future.

DEVELOPMENT IN INFANCY

No longer do we, as did William James, view the infant's world as a "booming buzzing confusion." We have learned that infants, from early on, attend more to novel than to familiar stimuli; they become bored with the old and excited with the new. They actively process information and they learn from experience in measurable ways. What we now know about the infant's perceptual and cognitive capabilities is truly impressive but more recently we have begun to learn about the infant's social and emotional development. The key concept in much of this research is attachment.

ATTACHMENT

It has been known since the early 1960s (e.g., Schaffer and Emerson, 1964) that infants at about 6 months begin to show a preference for the primary caretaker, usually the mother. Thus, the infant smiles more at the mother than at others, protests more when separated from the mother, makes more of an effort to be near the mother, and, perhaps most important, is more apt to explore new and threatening stimuli and situations when the mother is in the vicinity. This preference for the mother is not due simply to the infant's becoming perceptually able to discriminate the mother from others, since he can do this several months earlier, before any decided preference for the mother. There is evidence that the acute distress syndrome, sometimes shown by infants after admission to hospitals or residential nurseries, is probably due in large part to interference with attachment (Rutter, 1979). This suggests that attachment plays a central role in family social and emotional development.

Of the several theories that attempt to explain attachment, the most influential one is Bowlby's (1969) ethological-evolutionary view that it is an essential part of the "ground plan" of the human species (as well as many other species) for an infant to become attached to a mother figure. This figure can be the natural mother or anyone who acts as principal caregiver. The ground plan is fulfilled except under extraordinary circumstances when the baby experiences too little interaction with any one caregiver to support the formation of an attachment.

Though attachment may ultimately be a part of human nature, there are substantial individual differences in the ways attachment behaviors become patterned, and different experiences associated with each pattern. Most research has utilized a standardized laboratory assessment procedure, the "strange situation," in which children are classified according to the behavior shown when they are briefly separated from the mother, left with a stranger, and then reunited with the mother. Three main assifications of infants are obtained: (1) *Securely attached infants*—freely use the mother as a secure base from which to explore, show some distress and a reduction in exploration following separation, and, upon reunion actively seek and maintain contact with the mother until comforted and then return to play; (2) *Anxiously attached infants*—tend to show anxiety and little exploration even before separation, and are intensely distressed by separation; upon reunion they are ambivalent with the mother, seeking close contact with her and yet resisting contact (e.g., by squirming to get down, kicking, hitting, biting, batting away offered toys, or continuing to cry or fuss despite attempts at comforting (Ainsworth, 1978); and (3) *Avoidant* infants—rarely cry during separation and upon reunion they tend to ignore, look away, or turn away from the mother, or make abortive approaches.

There is increasing, though by no means conclusive, evidence that this classification is a meaningful one, with implications for the child's later psychological adjustment. Data show that these assessments of attachments are stable in middle-class infants from 12 months to 18 months of age (Waters, 1979). In poor homes, the changes in attachment were related to changing life events with mothers of infants changing from insecure (anxious or avoidant) to secure attachment reporting a significantly greater reduction in stressful life events during that period than did mothers of infants changing in the other direction (Vaughan et al., forthcoming). There is also considerable evidence that the assessments reflect individual differences in the infant's home behavior, in the infant's temperament at birth, and in the parent's behavior. Thus, infants who act in a securely attached manner in the strange situation also tend to do so in the home (Ainsworth et al., 1978); avoidant infants were often constitutionally "difficult" as newborns; and mothers whose personality or life situation make it difficult to be sensitively responsive (e.g., during feeding) often have infants who are anxiously attached (e.g., Water et al., 1979). Finally, infants who were abused or neglected by their parents show less secure attachment in the strange situation at 12 months than other children from the same community, although the differences disappeared by 18 months due to the addition of family support or out-of-home care (Egeland and Sroufe, forthcoming).

In examining the later consequences of these attachment patterns, children assessed as securely attached at 18 months were found—at 2 years and at 4-5 years—to be more enthusiastic, persistent, flexible, resourceful, and responsive to instructions, and less easily frustrated in solving problems than were insecurely attached children. And, those assessed as securely attached at 15 months turned out to be more competent in interacting with their nursery school peers (Arend et al., 1979). In general, the findings to date suggest that the quality of attachment in the infant's first year may be a significant factor in later development, and that the secure attachment pattern may be the ideal one. It must be noted, however, that all the research reported was done in the United States. A recent study by Grossman (1980) in West Germany suggests that cultural factors must be given more attention, for he found the avoidant pattern more prevalent in West Germany than is commonly reported in the United States. We can expect to see continued efforts to discover the long-term effects of different attachment patterns, and to understand how the patterns and long-term effects are influenced by changes in family arrangements such as mothers working outside the home and fathers serving as primary caretakers (L. Hoffman, forthcoming).

SOCIAL DEVELOPMENT

Aspects of social development in infancy other than attachment, have also become the focus of research. For example, some very interesting synchronies in mother-infant interaction have been discovered, using fine-grained "micro-analytic" techniques. When mothers "talk" to their newborn infants, the subtle body movements of the infant are often synchronized to the mother's speech sounds (Condon, 1977). When mothers and infants are presented with novel objects they are more likely to look at the same object than at different objects; analysis shows that this synchronization of visual attention results from the mother's tracking and imitating the infant's spontaneous looking (Collis and Schaffer, 1975). In interactions between mothers and their 3-4 month old infants, the signal for each participant to begin vocalizing is usually the *beginning* of the other's vocalization, with the result that both partners often interrupt each other and vocalize together (e.g., Parke and Sawin, 1977). By the time the infant is a year old, a dramatic shift has taken place and the interaction resembles adult conversation: the signal for each participant is the *end* of the other's vocalization (at least a pause), the mother and child take turns in their vocalizing, and they seldom interrupt one another (Schaffer, et al., 1977). This emerging body of research is beginning to reveal the processes by which the unique emotional aspects of the parent-child relationship, including the quality of attachment, develop.

There is rapidly growing interest in the origins of emotions. Considerable evidence now exists that at least five emotions—joy, surprise, sadness, anger, fear—may be universal in humans: that is, elicited by similar events in primitive as well as developed societies (see review by Ekman and Oster, 1979). There is also evidence that the discrete facial muscle movements involved in the expression of these fundamental emotions exist in newborn and even premature infants (Oster and Ekman, 1979). Furthermore, the entire facial patterns associated with these emotions are present by about 9 months (Izard et al.,1980). Because infants cannot talk, it is difficult to determine whether these facial patterns are associated with the corresponding *feelings*, although there is some pertinent evidence bearing on fear. In the first half-year of life some infants apparently do not show a fearful expression on their faces even in response to the acute pain of inoculations (Izard and Buchler, forthcoming). By 8 or 9 months, however, the infant's face takes on an expression of fear when the infant peers over the edge of a simulated cliff, and occasionally when a stranger approaches (e.g., Campos, 1978). In both cases the infant's heart rate accelerates when the face shows the fearful or anxious expression. This combination of appropriate facial and physiological responses suggests the infants may actually be experiencing fear. In view of the importance and previous neglect of the topic, we can expect research on early emotional experience to burgeon with respect to other emotions, as well as fear, and in older children as well as infants.

Another line of investigation addresses how and when a child first becomes aware of his own existence (e.g., Lewis and Brooks-Gunn, 1979). The usual technique is to have the mother unobtrusively apply a dot of rouge to the child's nose. An observer keeps track of how often the child touches his nose. The infant is then seated before a mirror and the observer notes whether the frequency of nose-touching increases. At about 18 months children show, by greatly increased nose-touching, that they recognize and coordinate the image they see in the mirror with the motion of touching their own body. This suggests that they have a sense of themselves as physical entities with a location in space. We can expect future research to extend the study of self awareness to other dimensions of the self that emerge as children mature. One dimension of particular interest is the sense of the self as having inner states (thoughts, feelings, intentions) and continuity over time. It is likely that these aspects of the self will influence, among other things, how the child experiences emotions and the nature of parent-child interaction. In addition, the nature and strength of the self concept may well influence achievements later in life. New research might indicate those conditions that support or inhibit the growth of a positive self concept.

Studies of attachment, communication, emotional expression, and the self in infants have established an informative basis for similar research with older children. We can expect the study of these phenomena to be extended to allow a consideration of the effects of age and experience.

SOCIAL-COGNITIVE DEVELOPMENT

A decade ago, developmental researchers interested in the study of cognition shifted from an exclusive concern with problem solving in the physical world to an equal interest in children's thinking about their social world. In part, this shift was prompted by the recognition that effective human interaction requires the ability to comprehend the thoughts, feelings, and intentions of others, as well as knowledge of the various frames of reference—beliefs, moral norms, "scripts"—that one shares with them. It became clear that cognitive theories based upon the physical world would not be entirely applicable to the social world.

DEVELOPING AN UNDERSTANDING OF OTHERS

Research has shown that children's comprehension of others moves through four distinct stages: from an initial confusion between the others and the self, to an awareness of other people as separate physical entities, to an ability to take the perspective of others, and finally to an awareness of others as having an independent existence and identity beyond the immediate situation.

"Person permanence" refers to the awareness of another's existence as a separate physical entity. Apparently the young infant lacks this awareness: objects, events, and people are not experienced as distinct from the self. Not until about 6 months does the infant organize the fleeting images making up his world into discrete objects and experience them as separate from his own biologically determined sensations. If a desired object is hidden behind a screen before the infant's eyes, the infant loses interest in it as though the object no longer existed. By 6 months, the infant removes the screen to get the object, indicating that he can then internally reproduce the image of an object and use the image as a guide to the object. By 18 months, the child can retrieve an object after a succession of "invisible displacements." (The experimenter places the object in a container that he then hides behind a screen and brings out empty after releasing the object.) This indicates that the child can evoke an object's image even when there is nothing in sight to attest to its existence. "Person permanence" apparently begins several months earlier (e.g., Bell, 1980); that is, by 1 year children can retain a mental image of a person even in the person's absence. The length of time that the child can do this and the number of persons that can be kept in mind obviously increase with age.

Although aware of people as physical entities, the young child does not yet know that they have inner states of their own, and he tends to attribute to them characteristics that belong to him. In Piaget's famous three-mountain landscape task, children below 6 years of age typically attribute their own viewpoint to a doll situated in various locations around the landscape. Piaget thought it was not until about 7 or 8 years that this "egocentrism" began to give way to the recognition that others have their own perspective. Research has since shown that certain aspects of Piaget's original task (e.g., the size and complexity of the objects displayed, their asymmetrical placement, the requirement of a verbal response) may have served to mask the ability of young children to see through the eyes of others. Three-year olds, for example, make very few errors when the display contains discrete, easily differentiated objects (small toys) and a verbal response is not required; that is, the subject indicates the other's point of view by manipulating an exact duplicate of the display (Borke, 1975). Two-year olds will turn a picture toward another person who asks to see it (Lempers, et al., 1977).

Recent research also suggests that with simple tasks, not only spatial but also cognitive role-taking competence appears much earlier than previously thought. Five-year-old children, for example, can infer whether another's actions are intentional or accidental. Four-year olds who watched short videotaped action sequences, accompanied by an explanatory audio portion, showed awareness that someone else would not understand the story when the sound was turned off (Mossler, et al., 1976). Four-year olds also chose appropriate birthday gifts for their mothers, rather than toys attractive to themselves (Marvin, 1974). This age group has also been found to take the listener's perspective into account in verbal communication tasks. They used simpler and more attention-getting language, for example, when talking to children much younger than themselves than when talking to peers or adults (Shatz and Gelman, 1973); and they were more explicit verbally when giving instructions to someone who apparently could not see, than to someone who could (Maratsos, 1973).

Finally, it appears that role-taking in familiar, highly motivating natural settings may precede laboratory role-taking by as much as a year or two, as evidenced in children's attempts at deception in the home (Hoffman, 1975c). Role-taking competence increases in accuracy and complexity throughout life, but the rudiments of this competence may be present before two years even though it may not be demonstrated in the laboratory until much later.

The next broad step in the child's development of a sense of the other is the recognition that the other has his own personal identity—his own life circumstances and inner states beyond the immediate situation. There has been no direct empirical research on this developmental stage, but there is evidence that the child's sense of his own continuing personal identity emerges somewhere between 6 and 9 years (e.g., Guardo and Bohan, 1971). It seems reasonable to assume that the sense of the identity of others would also be attained at about the same time, or a little later. The child should then be able not only to take the role of others and assess their reactions in particular situations, but also to generalize from these and construct a concept of their general life experience. This developmental change is obviously important in the formation of social attitudes, values, and belief systems, as well as in the acquisition of interpersonal skills.

COGNITIVE DEVELOPMENT AND MORAL THOUGHT

Piaget's belief that cognitive development contributes to moral maturity in children has stimulated considerable research. In his view the egocentrism of children under 7 or 8 years of age blinds them to crucial aspects of moral action such as the intentions that underlie harmful behavior. Recent research that minimizes the cognitive and linguistic demands on subjects, however, shows that even 4-year olds do consider intentions when making moral judgments (e.g., Keasey, 1978). They can also allocate rewards in a way that shows they can take into account both the other children's needs and their contributions to simple group tasks (Anderson and Butzin, 1978). In addition, they recognize that norms about the human consequences of action are more important than social conventions; for example, they strongly resist attempts to convince them that it would be proper to hit someone if the rules permitted, but they can readily be persuaded that if the rules were changed it would be acceptable to call teachers by their first names or dress in what they now consider to be unacceptable ways (Turiel, 1978).

The most influential cognitive-developmental theory has been advanced by Kohlberg (1969). In brief, Kohlberg views morality as developing in a series of six stages, beginning with a premoral one in which the child obeys to avoid punishment, and ending with a universal sense of justice or concern for reciprocity among individuals. Kohlberg regards each stage as a homogeneous, value-free, moral cognitive structure or reasoning strategy, and maintains that moral reasoning within a stage is consistent across different problems, situations, and values. Each stage builds on, reorganizes, and encompasses the preceding one, and provides new perspectives and criteria for making moral evaluations. Kohlberg has proposed that people in all cultures move through the stages in the same order—always forward, never backward, and never skipping a stage—varying only in how quickly and how far they progress. The impetus for movement derives from exposure to moral structures slightly more advanced than one's own. This produces a cognitive conflict that is resolved by integrating one's previous structure with the new one.

Kohlberg's theory has been criticized on many grounds, including, thus far, a lack of convincing empirical evidence. For example, the prediction that children are most influenced by moral reasons that are slightly more advanced than their own has not been confirmed. There is also evidence, contrary to the theory, that some people may regress in their level of moral reasoning over time. Kohlberg has acknowledged the lack of empirical support; he has modified the theory and relevant measuring instruments, and more recently has explored the usefulness of this approach in prisons and schools. His research has focused scholarly attention on the child's own active efforts to construct a moral viewpoint, and has formed the basis for extensive studies of moral development and related areas.

Damon (1977), working with considerably younger children than Kohlberg, has studied the development of moral concepts in four distinct areas: friendship, justice and fairness, obedience and authority, and social rules and conventions. To study concepts of justice, he asked 4–8 year olds what they thought would be a fair way to divide candy, money, or toys in several hypothetical situations (illustrated with pictures). In one story, three children worked together to make bracelets for an adult. One child made the most and the prettiest bracelets; another was the biggest child; and the third, the youngest, could not work as well or as fast as the others. The adult rewarded the group with ten candy bars. The children being studied were asked what they thought was the fairest way to divide the candy. In the responses to these and other stories, Damon found evidence of an age progression—from making little or no distinction between what a child would want for himself and what he thought was fair, to favoring an equal division, to recognizing that some children deserve more because they produced more, and finally, to understanding that several valid conflicting claims (e.g., between productivity and need) could exist and that a proper balance must be struck. Damon's work has opened new areas of investigation. Where do these concerns for justice and fairness, which are surprisingly sophisticated for young children, come from? How do the moral concepts of young children from different backgrounds compare? To what extent do these abstract concepts affect the child's actual behavior, for example, when the child's conceptions of justice conflict with his or her self-interest? Finally, how do these early conceptions and experiences influence moral behavior later in life?

TRAINING IN SOCIAL-COGNITIVE ABILITY

Many studies have been designed to improve children's perspective-taking skills. These efforts are based on the assumption that a person who sees things from the perspective of others is more likely to take their needs into account. In one of the most frequently cited of these studies (Chandler, 1973), chronically delinquent preadolescent children (11–13 years old) were asked to write skits involving persons of their own age, act out the skits, and have them videotaped. Each skit was repeated until each participant had occupied every role, and videotapes were reviewed at the end of each set. After ten 3-hour training sessions, the role-taking ability of these children had improved considerably, compared to control groups that received no training or simply watched animated and documentary films. More importantly, 18 months later the children who were trained showed significantly less delinquent behavior then the children in the control groups. Intervention-studies such as this have succeeded in improving performance in perspective-taking, and some, like the one just cited, found improvement in the children's behavioral adjustment.

An extensive program on the assessment and treatment of interpersonal problem-solving skills in children has been conducted at the Hahneman Community Mental Health Center in Philadelphia (Shure and Spivack, 1978). The program's aim is to improve three skills found to relate consistently to social adjustment in children: the abilities to generate alternative solutions to a given interpersonal problem situation, to foresee the immediate and long-range consequences of each alternative and to plan a series of specific actions to attain a given goal. The program first teaches a number of skills thought to be necessary for problem solving, namely linguistic concepts such as same-different and if-then, and the ability to identify basic emotions (happy, angry, sad). The rest of the program is devoted to a series of hypothetical and actual interpersonal problem situations. Teacher demonstration and puppet play are used to illustrate the training concepts, and whenever possible the problem-solving methods are applied to actual problems that arise among the children in school. The results of the program indicate that trained children improved on measures of alternative and consequential thinking, as well as on a measure of overt behavioral adjustment. Furthermore, the improvement was maintained at follow-up a year later, when children were rated by new teachers who were unaware of the experimental conditions.

Kohlberg's theory of moral development has also been used as a basis for moral education in the classroom. Since several of the moral stages are apt to be represented among the children in any classroom, it can be expected that in discussions of hypothetical or real-life moral conflicts, children at a relatively low stage will be exposed to more mature, higher levels of reasoning. The theory predicts that the resulting conflict will disturb their complacency and stimulate them to think seriously about the moral issue, perhaps for the first time, and to examine their own point of view in light of the more advanced one. It is assumed that the more advanced point of view would be judged superior and that the child would modify his own view accordingly. Evidence for the effectiveness of this technique is inconclusive, though no systematic assessments have been completed.

Training in various social-cognitive skills has been used with some success as the main ingredient in family therapy with adolescent delinquents (e.g., Parsons and Alexander, 1973). One reason for the success may be the emphasis placed on treatment within the family context, which facilitates both the learning of the social cognitive problem-solving skills and their application in the real world.

The results of these various intervention studies have been encouraging enough to warrant further probes of the effectiveness of training in social-cognitive skills on children with emotional disturbances, as well as normal and delinquent children.

Over the next few years we can expect to see further work on other aspects of children's social cognition; these include the development of the ability to think and reason about social institutions (e.g., money, politics, and government; see Furth, 1978); the development of the "social-comparison processes" by which information about others is employed in the construction of one's own self-concept (Ruble, forthcoming); the acquisition of "scripts" or ordered sequences of action appropriate to particular settings (Nelson, 1981); and the role of culture (Shweder, et. al., 1981) and of emotion (Hoffman, 1981b) in social-cognitive processes.

MORAL DEVELOPMENT, AGGRESSION, AND PROSOCIAL BEHAVIOR: INFLUENCE OF PARENTS, PEERS, AND TELEVISION

How do humans come to manage the inevitable conflict between personal needs and social obligations? It is now generally agreed that most people do not go through life viewing society's moral norms (e.g., honesty, justice, fair play) as external, coercively imposed pressures. Though initially external and in conflict with one's desires, social morality may eventually become part of one's motive system and have an effect on behavior even in the absence of external authority. This is not to deny that people may also be concerned about rewards and punishments and that some always respond selfishly, sometimes aggressively, when their desires are in conflict with social expectations. The challenge is to discover what kinds of experience lead children to respond to conflict in an internally controlled and moral manner, rather than with aggression or with a concern only for the relevant punishments and rewards.

Research on the socialization of norms and moral behavior has continued for over half a century, initially focusing on the influence of parents, and more recently expanding to consider the role of peers and television. Apart from schools, these three agents may well comprise the main environmental influences on the extent to which children become individuals who consider the needs of others or who act purely out of self-interest.

The contributions of social cognition and empathy to moral development are discussed elsewhere in this paper.

CHILDREARING PRACTICES AND MORAL INTERNALIZATION

Because the parent is the most significant figure in the child's life, psychologists have studied many facets of the parent's role—disciplinarian, affection giver, model. The moral norm studied in most of the research can be stated simply: People should in their actions consider the needs of others as well as themselves (e.g., they should tell the truth, keep promises, help others; they should not lie, steal, betray a trust, physically attack others or hurt their feelings). A moral norm is internalized if a person feels it is his own idea and often acts in accord with it, without thinking about the punitive consequences of doing otherwise. When an internalized moral norm is activated in a person, it has an obligatory quality; this does not guarantee that the person will always act morally, however, since his personal desires and situational temptations may be more powerful.

Moral internalization implies a weighing of personal desires against the moral requirements of a situation. Because earliest experiences with this type of conflict occur in discipline encounters with parents, and as often as 5–6 times per hour in early childhood (see, e.g., Wright 1967) parents' disciplinary procedures are expected to affect the child's moral development. Affection is important because it may make the child more receptive to discipline, more likely to emulate the parent, and emotionally secure enough to be open to the needs of others.

The relationships between types of discipline and moral indices such as resisting temptation and feeling guilty over violating a moral norm have been investigated extensively (see review by Hoffman, 1977). The findings suggest that moral internalization is fostered in several ways. One of the most effective is the parents' use of inductive discipline techniques. These techniques demonstrate the harmful consequences of the child's behavior for others, either directly ("If you keep pushing him, he'll fall down and cry") or indirectly ("Don't yell at him. He was only trying to help"). They become more complex as the child grows older, and may often include suggestions of reparative acts such as apologies. Moral internalization is also fostered by the parent's frequent expression of affection outside the specific discipline encounter. By contrast, a morality based primarily on the fear of external punishment is associated with excessive power-assertive discipline: e.g., physical punishment, deprivation of privileges, or the threat of these. The frequent use of power-assertion has been found to bear a strong relationship to the child's aggressive behavior toward his peers in preschool and elementary school settings. There is evidence, however, that the occasional use of power assertion—to let the child know that the parent feels strongly about something or to control the behavior of a child who is acting in an unreasonably defiant manner—by parents who usually employ inductions, may make a positive contribution to moral internalization (e.g., Zahn-Waxler, et al., 1979). There appears to be no relationship between moral internalization and love-withdrawal—techniques in which the parent simply gives direct but non-physical expression to his anger or disapproval of the child for engaging in some undesirable behavior (e.g., ignores the child, turns his back on him, refuses to speak or listen to him, explicitly states a dislike for the child, isolates or threatens to leave him). This research on moral internalization has focused on children ranging from 4 to 12 years of age, but there is evidence that the generalizations also hold for children as young as two years (Zahn-Waxler et al., 1979).

What about the effects of discipline on aggression? When the predominant component of the discipline is not induction but power-assertion, the child may perceive a clear threat to his freedom of action. This may arouse anger and the desire to restore freedom or "reactance" (Brehm, 1972). But it may also arouse fears of punishment if the child disobeys or expresses his anger. The child may then comply reluctantly, and displace his anger later toward less powerful figures outside the home, thus accounting for the research finding that power-assertion may contribute to the child's aggression toward peers. If the love-withdrawal component predominates, this may arouse anxiety over the possible loss of the parent's love. The child may then comply in order to avoid the loss and restore harmony. Techniques with pronounced love-withdrawal components are often used when the child expresses anger toward the parent, which may explain why love-withdrawal appears to contribute to the inhibition of anger (though not to moral internalization, as noted earlier).

Beginning with Freud it has been assumed that children identify with, and thus to some extent adopt, the parents' ways of evaluating one's own behavior. Psychoanalytic writers account for this in terms of anxiety over physical attack or loss of the parent's love. To reduce anxiety, the child tries to be like the parent—to adopt, insofar as possible, the parent's behavioral mannerisms, thoughts, feelings, and even the capacity for self-punishment and guilt over violating a moral standard. For other writers, the child identifies in order to acquire desirable parent characteristics (e.g., privileges, control of resources, power over the child).

The limited body of research on this topic suggests that identification may contribute to aspects of morality reflected in the parent's words and deeds (e.g., type of moral reasoning, helping others). Identification may not contribute to feeling guilty after violating moral standards (Hoffman, 1971), but this may be because parents rarely communicate their own guilt feelings to the child. Children also lack the cognitive skills needed to infer guilt feeling from the parent's overt behavior, and their motives to identify with the parent may not be strong enough to overcome the pain of self-criticism that accompanies guilt.

In the early 1960s, a number of experiments were conducted on imitation, which may be a necessary part of identification (e.g., Bandura and Walters, 1963). The results indicate that children will readily imitate an adult model who yields to temptation (e.g., leaves an assigned task to watch a movie), as though the model serves to legitimize the deviant behavior, but are less likely to imitate a model who resists temptation. Furthermore, when a child who makes moral judgments of others on the basis of the consequences of their acts is exposed to an adult model who makes judgments on the basis of the actor's intentions, the child shows an increased understanding of the principle of intentions, and the effect may last up to a year.

The tentative conclusion, pending more definitive research, is that identification may contribute to the child's adoption of moral attributes that are expressed in the parent's words or deeds and that do not require a great deal of self-denial. These moral attributes may then become internalized in the sense that the child uses them as criteria of right and wrong in judging others. The evidence thus far suggests, however, that identification, unlike discipline, may not contribute to the use of moral standards as an evaluative perspective for examining and controlling one's own behavior.

PEER INFLUENCES

Despite longstanding interest in the topic, peer interaction and its effects on the child have only recently been studied systematically. Much of the existing research is descriptive. For example, the child's interest in other children generally emerges in the second year and increases dramatically throughout childhood. In early childhood, there is more positive interaction between children of the same sex than between children of the opposite sex, but there is a gradual increase in mixed-sex interaction with age. Girls are more likely to help and share with their friends than with their acquaintances, whereas boys are more likely to compare abilities and compete with their friends than with their acquaintances.

There has been relatively little research on how interaction with peers affects the child's social development. The dominant theoretical orientation, advanced some fifty years ago by Piaget, is that unsupervised interaction with peers is essential for moral development. The reason, in brief, is that the absence of gross differentials of power provides children with the kind of experiences needed to develop moral norms and belief systems based on mutual consent and cooperation among equals. According to Piaget, these experiences—taking the role of others, participating in decision-making about rules and how to enforce them—are unlikely to occur in interactions with adults. A related formulation is that the parent's power over the child and the affectional bond between them operate as a powerful constraint against the child's expression of aggression toward the parent, a constraint that is absent in peer interactions (Hartup, forthcoming). There is evidence that children the world over express far more aggression toward peers than toward adults (Whiting and Whiting, 1975).

An opposite conception, however, is that unsupervised peer interaction may release the child's inhibitions and undermine the effects of previous socialization in the home. The research on peer influences provides some tentative answers concerning effects on aggression as well as insights on the broader impact of peer interaction.

First, there is support for the widespread assumption that the influence of peers increases as children grow older, with the peak of peer influence occurring in adolescence (e.g., Berndt, 1979). By early adolescence most children are aware of operating in two separate and sometimes conflicting social tracks—a peer track and an adult track. As for the direction of peer influence—do peer groups support or undermine adult values?—the answer is less clear. Most of the research on high-school subcultures finds broad areas of agreement with adult values, along with modest differences in emphasis such as greater stress on athletics and popularity rather than on academic achievement (e.g., Coleman, 1961). A significant exception is the use of drugs by adolescents, which is associated with the use of drugs by their friends (Kandel, 1971).

Regarding the role of peer interaction in socialization of aggression, the relevant experimental research (reviewed by Hoffman, 1977) indicates that if a child observes a peer who behaves aggressively and is not punished, the likelihood that the observing child will behave aggressively is increased; if the aggressive peer is punished, there is no measurable effect. This suggests that when children express aggression and are not punished, which often occurs in unsupervised peer settings, the effect may be to stimulate other children in the vicinity to act aggressively. Even if the children are punished, however, this may *not* serve as a deterrent to other children. Peer behavior (or at least its immediate impact) is more likely to weaken than to strengthen the inhibitions against aggression that the child has acquired in the home.

In a now classic observational study of 11-year-old boys in an experimental summer camp, Sherif et al. (1961) found that when two previously unacquainted groups competed in team sports, considerable animosity developed. Only working together on a superordinate goal introduced by camp counselors could reduce negative feelings. Other more recent studies with groups of younger children (Patterson, et al., 1967 and Strayer and

Strayer, 1978) suggest that aggressive behavior may emerge spontaneously and increase over time. Aggression may be reduced by an adult who alters the composition of the group or introduces new activities that stimulate cooperative interaction; or by the emergence of a dominance hierarchy in which some children develop a submissive pattern where they rarely challenge others. Thus, Piaget's contention that unsupervised peer interaction is conducive to moral development may not be entirely accurate. Certainly, with respect to the expression of aggression, peers appear to offer little guidance or control. Yet peer influences extend beyond the realm of aggressive behavior.

There is a body of laboratory research indicating that children will model peers on a variety of prosocial and problem solving behaviors. They will imitate peers with respect to appropriate sex role behaviors, altruism and helping, and affective response to humor (Hartup, forthcoming). This suggests that if groups can be structured to encourage these desirable behaviors in some individuals, others may act in a similar fashion. Furthermore, a variety of correlational studies have shown a strong negative relationship between early sociability (frequent, comfortable interaction with peers) and rates of delinquency and conduct disorders during adolescence and adulthood (Conger and Miller, 1966). There is also a growing literature documenting the effectiveness of peers in a variety of learning situations (Allen, 1976).

More research is needed concerning the role of peers in early socialization; for example, whether naturally forming, unsupervised peer groups, at various ages and in different segments of society, and operating in different settings, actually support or contradict the prevailing moral norms in society. What types of peer interaction are most conducive to prosocial behaviors? Do dominance hierarchies control aggression and if so at what cost? What is the contribution of childhood friendships to socialization? How do children manage the different and sometimes competing messages of peers, parents, and teachers? While it is surprising that such questions remain unanswered, research reported here indicates that peer influence will be the focus of important new research in the coming decade.

EFFECTS OF TELEVISION

Children of all ages spend many hours watching television and the trend in the amount of viewing time continues to be upward. Though wide variations exist depending on the segment of the audience surveyed, the average television set is on almost seven hours a day and children are among the most frequent viewers (Roberts and Bachen, forthcoming). Further increases can be expected with the growing use of cable television and videotape recorders. The effects of television viewing on the social and emotional lives of children have been the subject of considerable research. Most of this work has concentrated on violence and there are competing hypotheses concerning television's effects on this behavior. Some argue that watching filmed violence may *reduce* one's proneness to violent behavior because of the cathartic release provided. Others note that viewers, especially children, may learn by observing and imitating others. Thus, if a child sees television characters (especially those presented in a positive light with whom the child might identify) handling social conflict situations in a violent manner, he may respond in similar fashion when placed in a conflict situation. Repeated exposure may also blunt a sensitivity to violence, leading the child to under-estimate or fail to anticipate the painful consequences of aggressive acts.

Laboratory experiments have shown fairly conclusively that children exposed to a live or filmed model behaving aggressively (or helping or sharing) are apt to behave like the model shortly afterward. These studies suggest that when children observe a violent television program they are likely to have an immediate tendency toward aggressive behavior. The important social issue is whether television violence has long-term effects.

Researchers employing sample surveys have reported positive correlations between children's viewing of violent television programs and such measures of their aggression as amount of conflict with parents, frequency of fighting, and delinquent behavior. These correlations do not prove a causal connection, however. They may, for example, reflect a tendency for aggressive children to prefer violent television (Atkin et al., 1979) or yet a third variable may predict both aggressive behavior and the preference for violent television. Efforts have been made to overcome these limitations. In several studies where the samples were large enough to control for a variety of third variables, the relationship between viewing violence and aggressive behavior remained, although considerably weakened. A more stringent, though not perfect (Rogosa, 1980), technique for establishing a causal connection from correlational data is the "time-lagged" design. This method was employed by Eron et al., (1972), who found that children preferring violent television were rated as more aggressive in their behavior 10 years later.

Perhaps the most convincing way to test for long-term effects is to control the television viewing experience of children and observe their social behavior over an extended time in a natural setting. This is difficult, time-consuming, and expensive research. It demands the active cooperation of parents, schools, and other institutions. Control groups are required that are similar to the group watching the violent program, but that either watch a different program or participate in other activities (a rarely used control). Children in a control group may resent being deprived of their usual television fare and their possible anger at this change must be accounted for in analyzing the data. Children must be observed before, during, and shortly after watching the film, as well as some time later. The observer must not know whether he is observing experimental or control subjects. Few experimental studies of this type have been attempted. All of them lack at least one of these requirements, and the results are inconclusive. Feshbach and Singer (1971), in two studies where boys 9-15 years of age watched either aggressive programs (e.g., "Gunsmoke") or non-aggressive programs (e.g., "The Dick Van Dyke Show"), found no evidence that the violent programs led to an increase in aggressive behavior. Parke et al., (1977) employed a similar design in three studies of delinquent adolescent boys living in reformatories. No data on prolonged effects were reported, but aggressive behavior did increase during and immediately following the program for those who watched violent films. Other studies with younger children (Friedrich and Stein, 1973; Sawin, 1973) have found no, or highly qualified, evidence for an aggression-increasing effect of viewing televised violence.

In short, the data suggest some relationship between TV viewing and violent behavior, but studies employing the most stringent methods have not been performed. As one moves from the highly controlled but artificial laboratory experiments to observations in natural settings, the findings become less clear. The laboratory experiments clearly show that televised violence can have immediate violence enhancing effects. Correlational research indicates long-term effects but lacks the methodological rigor to support a causal inference. The field intervention studies show that children's aggressive tendencies in natural settings may be elevated while watching television violence and for a short time afterwards. But without further research, the nature of long-term effects is not certain. It may well be that intervening experiences will always make the proper determination of such effects difficult.

Researchers have recently initiated studies that focus on how television may influence children, irrespective of program content. One promising line of research by Collins (1979) has revealed children's inability to separate the central plot from peripheral details. His data suggest they often cannot make the proper inferences about motives underlying acts of aggression or the consequences of an act for the victim or the actor. What they retain is the aggressive act itself. This fragmentary experiencing of the film by young children is amplified by commercials, which frequently interrupt the sequence from act to consequence.

Other studies have begun to examine how a child's identification with television characters, such as "Mr. Rogers," may form a basis for influence. Can such programming encourage children's prosocial behavior, such as cooperation, sharing, and giving comfort? In one study (Friedrich and Stein, 1973), researchers showed four 20-minute prosocial films ("Mister Rogers' Neighborhood"), over a one-week period to kindergarten children, sometimes in combination with special training. The training consisted of (a) verbal learning in which themes from the program were labeled in storybooks and rehearsed by the children; (b) role-playing in which themes were rehearsed by the experimenter and the children using hand puppets; or (c) both verbal learning and role-playing. Exposure to the prosocial films without special training produced an increase in general content knowledge, but no increase in the child's overt helping behavior. With the addition of any of the training techniques, exposure to the prosocial film led to an increase in helping behavior.

The results of this and other similar studies (e.g., Coates, et al., 1976) seem to suggest that the prosocial behavior of young children may be increased through television only when the programming is supplemented by other training procedures. Since most television viewing will continue to occur outside of the educational context, further research is required on the type of programs that may increase children's prosocial behavior without requiring supplementary techniques.

Television has clearly become a significant force in children's early socialization. It can influence both aggressive and prosocial behaviors; however the evidence regarding the strength of these effects and their relation to program format and viewing context is limited and inconclusive. New research is required on television as a socialization agent—research that applies all the rigor of theory and method that have been applied to the study of the family.

MOTIVATION

Motivation has been a neglected area of study in child development research, although it is a central feature of many topics covered in this report. For example, to say that a child has internalized certain moral standards implies that the child is motivated to act in ways dictated by these standards; or to say that an infant seeks proximity is to assume some underlying motivation. In recent years there has been increased interest in research on topics which focus more directly on the motivational component of such behaviors. One area concerns the motivation for prosocial behavior where researchers have studied how children recognize another's pain or fear and how they acquire the desire to help. Other researchers have studied the development of motivations to delay gratification and to persist at certain tasks in the absence of external rewards. Knowledge concerning these latter behaviors will contribute to an understanding of how children learn to control impulses that conflict with long term goals, preparing them for the transition from play to work.

PROSOCIAL BEHAVIOR

In 1961 Kitty Genovese was brutally murdered in full view of over fifty people who made no attempt to help. This dramatic event drew public attention to the relation between private safety and public concern; it also prompted developmental researchers to study the emergence and motivation of prosocial behavior. Children gradually develop the capacities to help others in distress, to share possessions, and to cooperate with others on joint tasks. How are these behaviors learned and what conditions encourage their performance? Before turning to the developmental findings a note on research bearing directly on the bystander's behavior in the Kitty Genovese murder is in order.

Numerous studies have shown, contrary to intuitive beliefs, that a victim is more likely to receive help when there is only one witness than when there are many. Indeed, the research shows that people of all ages tend to offer help when they are the only witness and the need for help is clear (e.g., review by Hoffman, 1981a). Furthermore, the percentage of those who help is quite high. Children 8-10 years of age, for example, were found to attempt to help others in about half the opportunities to help that occurred in a naturalistic setting (Severy and Davis, 1971). This is consistent with Staub's (1971) findings in a laboratory experiment: 50% of the second-to-fourth graders left what they were doing to help a crying child in the next room. This is particularly interesting in view of the usual restraint shown by young children in laboratory studies. Although fewer sixth graders offered help in the same situation, half of those who had been given prior permission to enter the room did so, as did over 90% of a seventh-grade sample. The findings for adults are sometimes quite dramatic, in terms of both the frequency and speed with which the subjects aid the victim. Clark and Word (1972), for example, report that all their subjects rushed to help a man they heard fall and cry out in pain, and the average reaction time was less than 9 seconds.

Spontaneous helping and sharing have been observed in very young children. Rheingold et al. (1976) found that all 20 of the two-year olds they observed in a natural setting containing some ordinary household tasks (e.g., laundry to fold, scraps to sweep up) helped their mothers even though the mothers did not request any help. Eighteen of the 20 children helped an unfamiliar woman in the same situation. German children of the same age have been observed to engage in the frequent giving of gifts in natural settings (Stanjek, 1978).

Zahn-Waxler et al., (1979) have conducted the most extensive study of prosocial behavior. Mothers were trained to provide detailed observational reports on the child's response to another person's distress, and dictated their observations into a tape recorder soon after the incident. At 10-to-12 months of age, in a third of the incidents, the child just looked at the victim or did nothing; in a third to a half of the incidents the response was a frown, a sad face, a cry, and sometimes a visual checking with the parent. Over the next 6-to-8 months, as the behavior just described began to wane, there was an increase in concerned attention and behavioral attempts to help, such as patting or touching the victim. By 18-to-24 months children were bringing objects to the person who was suffering (e.g., toys and food to comfort someone sad, bandaids for many kinds of hurts), making suggestions about what to do, verbalizing sympathy, bringing someone else to help, and aggressively protecting the victim. They also tried alternative actions when one attempt failed. Although children occasionally tried to leave the scene, avoid, and at times even attack the victim, these reactions were rare. Some attempt to help was the rule. These findings are consistent with other findings that ". . . infants fully offer their own attention, affection, sympathy, help and possessions to others" (Rheingold and Hay, 1978: p. 119).

In studying prosocial behavior many researchers have examined the types of experiences that contribute to the tendency to help or share. The most frequently studied determinant of such behavior is exposure to models. Altruistic models do produce altruistic behavior and the effect varies depending on such model characteristics as warmth, power and hypocrisy. Unfortunately most of this research deals with the child's immediate response to the model, and as noted in discussing the effects of television, there is little evidence thus far of lasting effects. The childrearing research suggests that the parent may serve as an effective model for altruism but also that it is difficult to separate these effects from those of two other aspects of the parent's role: disciplinarian and giver of affection (Hoffman, 1975a). Altruistic behavior in fifth-grade, first-born children was assessed by peer ratings. Parental data were obtained in separate interviews with each parent. The altruistic children were found to have at least one parent who communicated altruistic values and thus may have served as a model, and one who frequently used inductive discipline techniques. Affection was an influential factor only in the mother-son pair.

Sharing and helping a younger child have been found to relate positively to cognitive role-taking in 7-year-olds (Rubin and Schneider, 1973). In one experimental study kindergarteners trained in role-taking skills were more likely to aid a younger child, an effect which persisted for a week (Staub, 1971). These findings are not surprising since a person should be more likely to help another if he can take the other's perspective. We must, however, not lose sight of the fact that role-taking is very likely a neutral skill, and it may therefore be expected to serve egoistic motives in situations presenting others as competitors as well as people in need.

There is considerable research on the effects of a person's well-being on his helping behavior. Children who are successful, popular, emotionally secure, or self-confident, or who have positive moods and feelings of success aroused in them experimentally, are more likely to help others. (e.g., Moore et al., 1973). A possible explanation is that fulfillment of the child's egoistic needs may reduce preoccupation with his own concerns and leave him open and responsive to the needs of others. Once aware of the other's needs, the child may feel an urge to help, share, or comfort the other. What underlies this prosocial motivation? Most social scientists believe that it is the human tendency to emphathize with others.

Empathy has been defined both as an awareness of another person's feelings and thoughts, and as a vicarious emotional response to others. The two conceptions interact, for the ability to respond vicariously depends partly on the extent to which one can infer another's emotional state. Conversely, vicariously aroused emotion supplies inner cues to the observer about what the other person is feeling. Thus, while cognitive considerations cannot be ignored, it is the emotional dimension of empathy that makes it salient to prosocial behavior.

The focus of most research on empathy has been on empathic distress—the empathic response to someone in distress. Hoffman (1978) has proposed a developmental theory of empathic distress that suggests a coalescence of empathic feeling with the child's developing sense of others. Initially the infant may experience distress in response to another's predicament but lack an awareness of who is actually in distress (*stage 1*). An 11-month-old girl, for example, on seeing a child fall and cry, may appear about to cry herself, put her thumb in her mouth and bury her head in her mother's lap, precisely her behavior when she is hurt. With the development of "person permanence" however, the child realizes that another person, not the self, is in distress although the other's inner states are assumed to be the same as her own (*stage 2*). An 18-month-old boy, therefore, may fetch his own mother to comfort a crying child, even when the friend's mother is present. With the emergence of role-taking capacities, empathy becomes a more accurate response to the other's feelings (*stage 3*) and finally, by late childhood, possessing conceptions of others as individuals with separate lives and identities, the child concludes that others may feel pleasure and pain apart from the immediately observable situation (*stage 4*). Hoffman's model describes how the development of empathy may rely partially on the child's cognitive awareness of others, which in turn is shaped by the child's overall level of cognitive development.

Levels of empathic response are assumed to form the basis of a motive to help others and, in general, research has supported this notion. Very young children typically react empathically to a hurt child although they sometimes do nothing or act inappropriately, while older children and adults also react empathically but this is usually followed by appropriate helping behavior (e.g., Sawin 1978). The level of empathic arousal and the speed of a helping act increase when there is an increase in the number and intensity of distress cues from the victim (e.g., Geer and Jarmecky, 1973). Further, the level of empathic arousal usually drops when one performs a helping act but the arousal continues at a high level if one makes no attempt to help (e.g., Darley and Latane, 1968).

This pattern of findings conforms to the hypothesis that empathic distress is a prosocial motive. Two qualifications are in order, however. First, though helping increases with the intensity of empathic distress, beyond a certain point empathic distress may become so intensely unpleasant—indeed, painful,—that one's attention is directed to the self and not the victim (Hoffman, 1978). Second, though people react empathically and offer help to most anyone in distress, they are more likely to do so if they see a similarity between themselves and the victim. Children respond more empathically to others of the same race or sex and, with cognitive development, to others perceived as similar in personality traits (Krebs, 1975). Despite these qualifications, current findings indicate that empathy is indeed an important component in the early appearance of prosocial behavior and deserves continued attention by developmental researchers.

DELAY OF GRATIFICATION

If a young child is offered the choice of a desired toy now or several such toys a week from now, the child will most likely take the one toy now. When he grows, up, he will most likely choose the larger reward even though it requires waiting. The motivation to postpone immediate gratification for future gain has long held a central place in Western social theory. It is viewed as essential to the Protestant Ethic and to saving and investing, and therefore as an individually adaptive and socially functional response in modern capitalist society. Since Freud, the ability to tolerate delay of gratification also has been viewed as basic to the transition from a state of being dominated by one's impulses to a state in which reality prevails, and therefore as a significant milestone in healthy ego development. It is the one ego function extensively researched with children.

In a typical study, the child chooses between an item available now and a clearly more desirable one available in the future. Early research focused mainly on socialization patterns, ethnic and social class differences, and personality correlates of choosing immediate or delayed rewards. The findings indicate that children in less developed countries are more likely to choose the immediate, less desirable reward than are American children. In this country, lower class children are more likely to choose the immediate reward than middle-class children, as are boys without fathers as compared to boys with fathers. Recent research focuses not on which choice is made but on the processes that enhance or detract from the child's motivation or ability to delay. Studies conducted with preschool children suggest that if the reward is physically present or if the child imagines that it is present, this operates against the maintenance of delay behavior. Because the reward constantly reminds the child of something he wants but does not have, it increases the frustration caused by the delay. Consequently, if given the opportunity, the child will terminate the delay and accept the less preferred item. Encouraging the child to engage in pleasant, distracting thoughts, however, facilitates delay (e.g., Mischel, 1981).

At first these findings seem to contradict the Freudian hypothesis that generating a mental image of the delayed goal object enables the child to "bide the time" until the object becomes available, hence to tolerate delay. To account for this apparent discrepancy, Miller and Karniol (1976) noted that Mischel's experiment involved a voluntary, self-imposed delay, whereas Freud was concerned with externally imposed delay situations such as those where the mother leaves the infant. They found that in a voluntary delay condition like Mischel's, third-grade children exhibited more frustration and engaged in more distracting behavior when the reward was salient. Using a modified design in which delay was externally imposed, however, the opposite pattern was found. In addition these researchers found that increasing the duration of the delay resulted in the child's paying less attention to a reward-relevant cue (a clock) when the delay was self-imposed, but not when the delay was externally imposed. These findings suggest two types of delay processes: (1) when delay is externally imposed and compulsory, salience of the desired object helps the child to anticipate having it and thus reduces frustration; (2) when delay is voluntary, salience of the object increases the child's temptation to take what is available now, and the child tries to reduce the temptation by diverting his attention and doing other things.

When Mischel's preschool subjects were allowed to choose what happens during the waiting period—by pushing buttons they could determine whether the object, a picture of the object, or nothing at all would remain in front of them—they typically chose to have the object in front of them. This, as we have seen, is least functional from the standpoint of enabling them to tolerate delay. By 6 or 7 years of age, however, children rarely chose to have the object present, thus demonstrating that they were aware of the fact that it would interfere with their ability to delay.

This research advances our understanding of the development of the ability to delay gratification but is limited to short-term delayed gratifications. More research is needed to determine the extent to which contemplation of future rewards contributes to prolonged study or work. Factors such as faith or trust in the future may be more significant in delays of this kind.

INTRINSIC MOTIVATION

Progressive educators have long held that the schooling process often fails to capitalize on children's spontaneous interest in learning and exploration and indeed may even undermine this interest. One study found that preschoolers and 6–7 year olds lost some of their initial spontaneous interest in a play activity (drawing, listening to a story) after being promised a reward for engaging in that activity (e.g., Reiss and Sushinsky, 1976). In another study, preschool children lost interest in an activity after performing it in front of a television camera (Lepper and Greene, 1975). There also is evidence that the adverse effects of rewards on motivation may be reflected in poor performance on certain tasks. Sixth-graders who like to help younger children were found to be more demanding and critical, less patient, and less effective (their pupils did more poorly) in teaching a sorting game to first graders, if promised movie tickets for this helping activity, than if no reward was promised (Garbarino, 1975).

The usual explanation for these negative effects of extrinsic rewards is that the child views himself as engaging in an activity only to obtain rewards, not because he likes the activity. An alternative explanation is that the promised reward leads to reduced interest in the activity because the reward served as a novel, distracting, and competing stimulus. This latter view is supported by the finding that no reduction in intrinsic interest in 5-year olds occurred when the reward did not compete with the activity (Reiss and Shushinsky, 1975). Furthermore, although rewards that are logically unrelated to the activity may decrease intrinsic interest, there may actually be an increase in intrinsic interest when the rewards are an inherent part of the activity, e.g. winning money in a "stock market" game (Kruglanski, 1975). An alternative explanation is that the activities that interest children are often linked to their self-system (e.g., are often a source of pride). Rewards provide an external motivation that may undercut this self-motivation. Therefore if a reward were given only for superior performance, it might link up with the self-system because it communicated something about the person's competence. Evidence for this view was obtained by Rosenfield et al. (1980) who found that intrinsic interest in an activity was increased by rewards that were made contingent on the quality of the subject's performance.

Further research is needed, however, to disentangle the effects of the child's age, the type of task, the relation between the external reward and the task, and between the reward and the child's self-system. What we can say at present is the evidence suggests that offering rewards may often undermine the child's intrinsic interest in a task and have a detrimental effect on performance.

If rewards often reduce intrinsic motivation, where does the intrinsic motivation originate? Lepper and Greene, (1975) suggest that under certain conditions external rewards may actually contribute to intrinsic interest over the long term. For example, external rewards may be necessary to get the child involved in activities that may later become intrinsically attractive once the child has attained some minimal level of mastery (e.g., playing a musical instrument). This seems to suggest that there may be an optimal balance between external incentive and the child's initial level of interest in an activity.

A study by Miller et al. (1975) suggests that intrinsic motivation may sometimes be produced by the simple expedient of attributing it to the child. In an attempt to teach fifth-grade classes not to litter, and to clean up after others, an attribution group was told once a day for eight days that they were neat and tidy people. A persuasion group was told with the same frequency that they "should be" neat and tidy and were given reasons for doing so. Attribution proved considerably more effective in modifying littering behavior, as measured both on the tenth day and two weeks later. The investigators suggest that attribution may have worked because it implies something positive about the child and thus provides a positive link to the self-system, whereas persuasion implies something negative.

Research on delayed gratification and intrinsic motivation illustrates how children's early emotional involvement in physical and cognitive tasks may establish the basis for more enduring motivational characteristics. While these motivations undoubtedly contribute to children's growing adaptive abilities, the findings thus far provide only a glimpse of how they develop the emotional capacities essential to satisfying and productive activities later in life.

SEX-ROLE DEVELOPMENT

Many of the recent changes in society reflect new attitudes about expectations for males and females. Women are entering the labor force in increasing numbers and are at times the major breadwinner. Men are increasingly expected to share in the childrearing and housework. The high divorce rate has led to many more one-parent families. There is an increasing concern with equity between the sexes at work and at home. These changes have raised questions about their psychological impact on families, especially children. For example, what is the effect of socializing children for one type of adult role and then, when they are older, expecting something different? These latter effects will be discussed in subsequent sections. This section considers how changing sex roles have stimulated theorizing and basic research on sex differences and the processes underlying them.

SEX DIFFERENCES IN BEHAVIOR

There are different views about which sex differences actually exist. Most researchers agree with Maccoby and Jacklin (1974) that the differences in physical aggressiveness, male superiority in visual-spatial abilities and mathematical skills, and female superiority in verbal skills are well substantiated. Others would add that females are also more apt to seek help and reassurance, and, at least when they are young, to comply with adult demands and requests (Block, forthcoming). Recent research also indicates that females are better able to infer from facial and other cues what other people are feeling (Hall, 1978), and more apt to respond empathically to the feelings of others (Hoffman, 1977b). The prevailing view is that, with one exception, these differences are due to socialization experiences. The one exception is the sex difference in physical aggression, which may have a biological basis. Even with aggression, though, socialization may play a role. Boys receive less affection than girls, and are disciplined more often with power-assertion and less often with induction (e.g., Zussman, 1978)—the pattern noted earlier as fostering aggression.

The predominant belief since Freud is that children identify with the parent of the same sex for reasons that initially have nothing to do with sex roles. Psychoanalytic writers attribute this to the child's anxiety over physical punishment or loss of parental love: to avoid anxiety, the child strives desperately to be like the parent and thus acquires not only a conscience but also an appropriate sex-role identity. According to social-learning theories, the child emulates the parent for different reasons; for example, they acquire the parent's power, mastery, and other resources. There is little pertinent research, and the results are not clear. When children are asked to name the person they most want to be like, they usually pick the parent of the same sex (e.g., Hoffman, 1975b). This is especially true of boys. When we observe who they actually imitate in a laboratory situation, however, they are apt to imitate the parent who is the more dominant figure in the home (makes more decisions) regardless of that parent's sex (e.g., Hetheringon, 1965). The one case fitting the pattern expected by the identification theorists is that of girls in traditional homes in which the father is dominant: the girls who imitate their mothers generally show more feminine sex-role preferences than girls who imitate their fathers (Hetherington, 1965).

Although it has also been assumed that children imitate peers of the same sex, the research does not provide clear support. The reason may be, as Perry and Bussey (1979) suggest, that children do not imitate any single person just because that person is of the same sex, but instead first watch the actions of *many* persons of each sex and abstract a concept of what is appropriate behavior for males and females. They then use this concept as a guide for governing their own behavior. Perry and Bussey's research shows that this may happen in 8- and 9-year olds, but what about children who are too young to do the necessary abstracting? The most likely explanation lies in the socialization pressures placed on the child.

Research on sex-role socialization (reviewed by L. Hoffman, 1977) includes several findings: (1) The stage is set for sex differences even before birth. In most countries, including the United States, there is a strong preference for having male children. (2) From an early age, parents play more roughly and vigorously with infant boys than girls. Since boys are no sturdier, this may reflect the cultural stereotype that girls are more fragile. (3) Boys are given more encouragement by parents for independent exploration of the environment; for example, they are allowed to roam over a wider area of the community without special permission. (4) Different toys are made available and different household tasks are assigned. For girls, the toys and the tasks are in keeping with the traditional mother role. Boys are given toys that represent the world of work and assigned tasks typically carried out by fathers. This traditional division continues to exist despite recent changes in social expectations (e.g., fewer parents now think that shoveling the walk and washing the car should be done only by boys, or that housework should be done only by girls). (5) Although both sexes are encouraged to do well in school, greater pressure, especially by fathers, is put on boys to achieve. This is shown dramatically in an experiment in which the parents separately taught their children several cognitive tasks. Both parents used the same basic teaching strategy, but fathers showed more concern with performance, especially of their sons. With their daughters, the fathers were concerned less with performance and more with the interpersonal aspects of the situation; for example, they were more protective and tried to make the situation more enjoyable.

Parents apparently respond negatively to obvious forms of cross-sex behavior, especially in boys. This is demonstrated by the cleverly designed experiment of Langlois and Downs (forthcoming). Children were asked to play with a set of sex-typed toys. The female set included a dollhouse with furniture, pots and pans, and dress-up clothes. The male set included an army game with soldiers and vehicles, cars, and cowboy outfits. The instructions were to play with one or the other set of toys "the way boys do" or "the way girls do." As soon as the children began to play, the child's mother or father entered the room. Fathers were more concerned than mothers when the child played with the sex-inappropriate toys and they reacted more negatively when their sons did this than their daughters. In addition, boys who played with feminine toys received more negative reactions from a male playmate than did boys who played with masculine toys. Female playmates responded the same way regardless of the toys the girls played with. This study suggests that boys may experience more pressures for sex-appropriate behavior from parents and peers than girls do.

There is some evidence, contrary to Freudian theories, that females are more morally internalized than males. In a national survey, fourteen- to sixteen-year olds were asked why parents made rules and what would happen if there were none. Boys more often said parents made rules to keep children out of trouble (Douvan and Adelson, 1966). In an experimental study, females more often resisted instructions to violate a norm against harming others (Kilham and Mann, 1974). This finding is particularly remarkable because females more often conform to instructions in experiments not bearing on moral issues (Wallach and Kogan, 1959). In a field experiment, females more often returned valuable items found in the street when no witnesses were present. When others were present, there were no sex differences (Gross, 1972). In an extensive study of 10–14 years olds in the Detroit area, females gave strong evidence of having more internalized moral orientations than males. They were more likely to feel guilty when they violated a moral norm, for example, whereas males were more likely to show fear of external punishment (Hoffman, 1975b). Females also revealed a more humanistic moral orientation, for they placed a greater value on going out of one's way to help others. The males placed a higher value on achievement, but this appeared to reflect an orientation toward self-gratification rather than a moral orientation.

The sex difference in moral orientation may be due partly to childrearing differences, since parents of girls more often use inductive discipline and express affection (Zussman, 1978). But the same pattern of sex differences in moral orientation has also been found for the parents. This suggests the need for a broader explanation. One possibility is that because females traditionally have been socialized into the "expressive" role—to give and receive affection and to be responsive to other people's needs—they are well equipped to acquire humanistic moral concerns. Boys are socialized this way too, but as they approach adolescence they are increasingly instructed in the "instrumental" character traits and skills needed for occupational success, which may often conflict with humanistic moral concerns. Burton (1972), for example, found that under high achievement pressure, parents may sometimes communicate that it is more important to succeed than to be honest.

These findings, if substantiated, are potentially important. Since our society still tends to define masculinity largely in terms of achievement and success, the indoctrination of adolescent boys into the male role may often conflict with the moral norms that they may have internalized in childhood. Furthermore, these pressures may be powerful enough to override the moral norms and dull the edges of sensitivity to the needs of others. The instrumental world, in short, may often operate as a corrupting influence on the morality of males. It is important to know whether this will also happen to women as more of them assume the instrumental role in society and if it does, what will the implications be for the moral socialization of children in the future?

ACHIEVEMENT AND FEAR OF SUCCESS

Contrary to the cultural stereotype that males are more motivated to achieve than are females, research does not confirm sex difference in achievement motivation. The achievement measures (e.g., preference for difficult tasks, achievement themes in response to school-related projective stimuli, level of aspiration), however, do not require the subject to choose between achievement and other values. In one study that did require a choice (Hoffman, 1975b), children and adults rated the importance of 18 personal attributes, including "trying your best in everything you do" and "doing well in school (work)." In five large, independent samples (one 5th grade, two 7th grade, two adult), the males chose these achievement items more often than the females, who preferred items pertaining to consideration for others. Thus males do appear to place greater value on achievement, although the previous research indicates females are as likely as males to have achievement motives aroused in situations that call for achievement and do not conflict with their other values.

Some research suggests that women may develop a fear of success. In one study, fear of success was measured for children in the fifth through eleventh grades who performed several tasks under competitive and noncompetitive conditions (Romer, 1975). No sex differences or age trends in fear-of-success scores were found. However, at the two older grade levels, girls who feared success performed more poorly in the competitive conditions. In fact, most research on fear of success has focused on college students and the only long-term follow-up of college women (L. Hoffman, 1977) found that fear of success dropped significantly over a nine-year period. If achievement motivation and fear of success are important sex differences, and the research is quite inconclusive on this point (Zuckerman and Wheeler, 1975), then there is a need for more investigations of their childhood antecedents.

SEX-ROLE PREFERENCE AND PERSONAL ADJUSTMENT

There is increasing evidence that traditional sex-role socialization may not be conducive to healthy personal adjustment. In an attempt to test this proposition, Bem (1975) found that college males with strong masculine preferences showed an impaired capacity for tenderness (in interacting with a kitten) and females with strong feminine preferences found it difficult to resist irrational social pressures to conform. Androgynous subjects of either sex showed both types of competence. Indirect evidence comes from a study by Rosenfeld (1975), who presented four masculine and feminine sex-typed toys (controlled for relevant variables such as cost), to children in grades one to three and asked them to "think of the strangest, most exciting, and most interesting way you can for changing this toy so that boys and girls will have more fun playing with it." Both boys and girls responded with far more varied approaches for improving the masculine toys. If feminine toys thus lack inventive potential, they may elicit little creative competence, and parents who encourage girls to play with them may do them a disservice. There is evidence from parental reports and home observations of 18–24 month old infants (e.g., Fagot, 1974), and observations of adults interacting with a 3-month-old infant introduced as a male or female (Seavy, et al., 1975), that parents still encourage girls to play with feminine toys, although they sometimes do offer them masculine toys.

Life-span criteria can also illuminate the deficiencies of traditional sex-role socialization, for it is clear that the role requirements of adulthood may conflict with the socialization goals of earlier periods. For example, same-sex interests and traits peak in adolescence, and data from the Berkeley Growth Study showed that boys rated highly masculine in adolescence also scored high on adjustment but lost ground later in life when masculine attributes (e.g., athletic prowess) became less important. Apparently, due to the high status associated with masculinity, they found it less necessary to develop interpersonal and intellectual skills and were consequently disadvantaged as adults. Such discontinuities have always existed but current changes in sex roles may intensify the effects. Douvan (1975) argues that the trend toward de-differentiation of sex roles poses more problems for males than females. The new challenge for girls to develop and sustain individual achievement goals does not introduce a radically new motive (for most), nor require them to deny previously developed motives, since early schooling trained them to achieve, compete, and use their individual competencies. Besides, in the emerging postindustrial era, the emphasis is shifting gradually from production and technical skills to the manipulation of words and ideas and to interacting with people—skills similar to those involved in traditional female socialization. The challenge is greater for males because they are increasingly expected to contribute their share to the more "expressive" side of family and social life. This implies the expression of motives and interests that may have been forcefully socialized out of them in childhood. It is possible, therefore, that traditional masculine socialization may be a handicap for boys growing up during this period of cultural transition.

Androgynous socialization may provide the best preparation for both males and females to handle changing role demands throughout the life cycle. But the existing research findings are limited and serious questions have been raised about whether androgyny is in fact a satisfactory alternative to traditional sex-role identity (see especially Baumrind, 1980). Consequently, the study of sex roles will continue to be an important focus for developmental research.

THE EFFECTS OF MATERNAL EMPLOYMENT[2]

The phenomenon of mothers working outside the home has increased from a rarity to the point where it is virtually the norm, and there is every indication that this trend will continue (U.S. Department of Commerce, 1979). For the last 10 years, over half the mothers who live with their husbands and have school-age children have been employed and almost 42% of the mothers of preschoolers are now employed. Employment rates are higher for mothers in single-parent families, and such families are also increasing.

What effects will this increased maternal employment have on children? Preschool children of working mothers will spend more time with another adult during working hours. Even when children enter school their lives at home after school will differ considerably from children whose mothers do not work. There is evidence that they will spend more time alone and watching television. Initially these changes influence the quantity of time a mother can spend with a child, but not necessarily the quality. Owing to a decrease in family size and an increase in efficiency in household operation, it is not certain that today's children with working mothers actually receive less attention than did children in the past with mothers at home. There is evidence, for example, in a study of middle-class preschoolers, that today's working mothers may spend as much time in one-to-one mother-child contact as today's nonworking mothers (Goldberg, 1977). Even if children of working mothers did receive less attention, the effect on their social and emotional development would not necessarily be negative. There is some evidence that educated nonworking mothers may over-invest in their children, bringing on an excess of worry and insufficient encouragement of independence (Birnbaum, 1975). Mothers who work and are satisfied with their work role, by contrast, may actually find their effectiveness as parents enhanced (e.g., Gold and Andres, 1978b). In the final analysis, however, one must consider how children's altered life style, due to maternal employment, influences their development. As the effects can vary with the stage of development, this research will be reviewed with reference to the child's age.

Unfortunately, relatively little is known about the effects of maternal employment on infants and young children. A major concern at this age is the impact of day care arrangements that must substitute for the mother's attention. In general most studies have not demonstrated significant adverse effects of quality day care for infants (e.g., Rubenstein and Howes, 1979). In a longitudinal study by Moore (1975) begun in the 1950s, it was found that boys who received full-time mothering during their preschool years, compared to part-time arrangements, were more intellectually able but also more conforming, fearful, and inhibited as adolescents. Hetherington (1979), in studying the effects of divorce on 4-year olds, found that the adverse effects of divorce were diminished when the mother had been employed before the divorce. The mother's job helped her to cope with the divorce more effectively, both psychologically and economically. Difficulties arose, however, if the mother started work at the time of the divorce. While the new job helped the mother by providing self-esteem and new social contacts, it also disrupted established routines and added to the child's losses.

There is an urgent need for more research on the effects of maternal employment on infants and preschool children. Studies of older children suggest that this work should focus on what is happening to the child when the mother is at work. Is the child in a stimulating, affectionate, and stable environment? In what way is that environment different from the one that would exist if the mother were at home? Would the mother be resentful or inattentive or less effective than the substitute caretaker? What is the quality of the mother-child interaction when the mother is with the child?

Research findings indicate that in the working mother's home there is a less traditional division of labor between husband and wife. Though the woman maintains the larger share, the husband participates more in housework and child care. He is less likely to have a second job and thus has more time for the family. The children are more likely to have household responsibilities. Yet the after-school home care of these children is an issue of some concern, especially among adolescents. Parents employ a variety of strategies, from using family members as baby-sitters to self care. Remarkably, the vast majority of studies to date have shown that maternal employment has little negative effects on children's development during the school years, and would appear sometimes to have a positive effect. The pattern for daughters is particularly clear. The daughters of working mothers are more outgoing, independent, active, highly motivated; they score higher on a variety of indices of academic achievement, and appear better adjusted on social and personality measures. For sons, the needs of adolescence seem well suited to maternal employment. In a study by Gold and Andres (1978a), both the sons and the daughters of working mothers showed better social and personality adjustment, a greater sense of personal worth, more sense of belonging, better family relations, and better interpersonal relations at school. It must be noted that none of the studies of maternal employment during adolescence focused on situations where mothers had recently become employed, however. There is a need for new research on the effects of maternal employment that accounts for the timing and length of employment as it relates to children's developmental stage.

Although juggling the worker and home-maker role can become difficult and the resulting maternal stress can be detrimental to a child of any age, studies indicate that the mother's employment can have positive effects as well, particularly on middle-class girls in later childhood and adolescence. What is known suggests that the mother's employment is not an inevitable loss for the infant or young child, but neither does it appear to be irrelevant. New research is required to understand more fully how alternative child care arrangements meet the needs of infants and children at different ages. While most studies to date indicate only minimal negative effects of maternal employment upon children's social and emotional development, the evidence must be considered inconclusive. New studies must assess a wider range of social and emotional factors and follow children for longer periods of time.

IMPACT OF DIVORCE ON CHILDREN[3]

The rate of divorce involving children in the United States has increased dramatically in recent years. It is estimated that 40% of the current marriages of young adults will end in divorce and that 40-50% of children born in the 1970s will spend some time living in a single-parent family. The average length of time spent by children in a single-parent home as a result of marital disruption is about six years. The majority of these children reside with their mothers, with only 10% living with their fathers even though this proportion has tripled since 1960. Living with the father is most likely to occur with school-aged rather than preschool children.

Early research on divorce revealed it to be not a single event but rather a sequence of experiences involving a transition in the lives of children. This transition involves a shift from the family situation before divorce to the disequilibrium and disorganization associated with separation and divorce, through a period when family members are experimenting with coping mechanisms—some successful and some unsuccessful—for dealing with their new situation. This is followed by the reorganization and eventual attainment of a new pattern of equilibrium in a single-parent household. Finally, for most children, within five years of the divorce there is also a period of reentry into a two-parent family involving a stepparent and necessitating further alterations in the family functioning. Any assessment of children's adjustment to divorce and of the factors influencing that adjustment must consider this total sequence of divorce experiences.

Initially divorce may involve relief from a destructive family relationship, offering the child an escape from one set of stresses and an opportunity for personal growth. Yet almost all children experience divorce as painful. While some children are able to recognize later that the divorce had constructive outcomes, initially they undergo considerable emotional distress with family dissolution.

Numerous studies have explored how divorce alters the patterns of family interaction and how these interruptions create both stress and opportunities for growth. This research has documented a pattern that has become familiar to many in our society. The single parent household often experiences a downward shift in economic status. The head of the household, usually the mother, experiences extreme psychological stress, and the reallocation of roles and responsibilities within the family often leads to a chaotic lifestyle. Physical relocation may occur, causing shifts in the family's social network. The mother may become employed and therefore absent from the home for extended periods. The immediate loss of frequent contact with one parent is often accompanied by open recognition and expression of parental conflict, sometimes compelling the child to be loyal to one parent over the other. These changing conditions are important to a child's development primarily because they modify the basic social and emotional interactions between parent and child.

The parents' response to divorce and the quality of the child's relationship with both parents immediately after divorce have a substantial effect on the child's ability to cope and adjust (Hetherington et al., 1976). In the first year after divorce, parents often are preoccupied with their own depression, anger, or emotional needs and are unable to respond sensitively to the wants of the child. During this period, divorced parents tend to be inconsistent, less affectionate, and lacking in control over their children (Hetherington et al., 1978). However, they often recover markedly in the second year.

Regardless of the extent of the noncustodial parent's contact with a child, the well-being of the divorced mother and the quality of her maternal behavior become central to the child's adjustment. The mother's sense of competence, self-esteem, and happiness is modified by the behavior of her children, particularly her sons. The mother who must cope with too many young children or with acting-out, non-compliant behavior in sons becomes increasingly distressed and inept in her parenting. Divorced adults have more health and emotional problems, even after the initial crisis period, than do married adults (Bloom, et al., 1978). This suggests that the child may be coping with a mother who is not only confronting many stresses but who may be physically and psychologically less able to cope with adversity.

Divorced mothers often expect their children to fulfill some of the functions of the departed father. There may be great pressure for elementary-school-aged children and adolescents to function in a mature, autonomous manner, and the mother may even rely on the children for emotional support and assistance with problems of daily life. Weiss (1978) has described the phenomenon of great self-sufficiency and rapid maturation that often occurs in one-parent families. If the mother is not making excessive or inappropriate demands for emotional sustenance, her greater openness about concerns and plans can lead to compassionate relationships with her children. However, being pushed toward early independence and the assumption of adult responsibilities can lead some children to feel overwhelmed by unsolvable problems, incompetence, resentment about lack of support and unavailability of mothers, and occasionally to precocious sexual concerns (e.g., Kelly, 1978).

While these patterns of interaction are predictable outcomes of divorce, evidence about the influence of these changes on a child's development is conflicting and still quite limited. It is clear, however, that the effects of divorce vary considerably depending upon the particular history and characteristics of the individual child. The data suggest that most children can cope with and adapt to the short-term crisis of divorce within a few years. However, if the crisis is compounded by multiple stresses and continued adversity, developmental disruptions may occur. The longer term adjustment of the child is related to more sustained or concurrent conditions associated with the quality of life in a household headed by a single parent. These conditions include—alterations in support systems; the increased salience of the custodial parent; the lack of availability of the noncustodial parent; the presence of one less significant adult in the household to participate in decision making, to serve as a model or disciplinarian, or to assume responsibility for household tasks and child care. Finally, there are changes in family functioning related to continued stresses associated with practical problems of living, such as altered economic resources.

Children's responses and adaptations to divorce vary widely in quality and intensity. Some children exhibit severe or sustained disruptions in development; others seem to sail through a turbulent divorce and stressful aftermath and emerge as competent, well-functioning individuals. Although there is increasing interest in the relative vulnerability or invulnerability of children to psychosocial stress (e.g., Garmezy, 1975) this issue has not been systematically explored in relation to divorce. It seems likely that temperamental variables, past experience, and the child's age all contribute to individual differences in coping with divorce.

The child's adaptation to divorce appears to vary with age. For example, the young child is less able to appraise accurately the divorce situation, the motives and feelings of the parents, his or her own role in the divorce, and the array of possible outcomes. As a result the young child is likely to be more self-blaming in interpreting the cause of divorce and to distort perceptions of the parents' emotions, needs, and behavior, as well as the prospects of reconciliation or total abandonment (e.g., Tessman, 1978). Although most adolescents experience considerable initial pain and anger when their parents divorce, once the immediate trauma is over they are able to assign responsibility for the divorce more accurately, to resolve loyalty conflicts, and to assess and cope with economic and other practical exigencies (e.g., Wallerstein and Kelly, 1975). This adaptation is often accompanied, however, by premature and sometimes destructive disengagement from the family. If the home situation is particularly painful, adolescents (more than younger children) do have the option to disengage and seek gratification elsewhere, such as the neighborhood, peer group, or school.

The impact of marital discord and divorce is more pervasive and enduring for boys than for girls (e.g., Hetherington, et al., 1978). Disturbances in social and emotional development in girls largely disappear within two years of divorce, although they may reemerge at adolescence in the form of disruptions in heterosexual relations (Hetherington, 1972). Although boys improve markedly in coping and adjustment in the two years after divorce, many continue to show developmental deviations. Boys from divorced families, in contrast with girls from divorced families and children from intact families, show a higher rate of behavior disorders and problems in interpersonal relations, both in the home and in the school with teachers and peers. Although boys and girls both show an increase in dependent help-seeking and affection-seeking overtures following divorce, boys are more likely also to show more sustained noncompliant aggressive behavior in the home (Hetherington et al., forthcoming).

Reasons for these sex differences are complex. Recent divorce studies show that boys are more likely to be exposed to parental battles. Following divorce, they are more likely to confront inconsistency, negative sanctions, and opposition from parents, particularly mothers. In addition, boys receive less positive support and nurturance; and in the period immediately following divorce they are viewed more negatively than girls by mothers, teachers, and peers (e.g., Hetherington et al., 1978). Divorced mothers of boys report feeling more stress and depression than do divorced mothers of girls (e.g., Colletta, 1978). It is possible then, that boys are exposed to more stress, frustration, and aggression and have fewer available supports.

It is known that when children experience only a single stress, there is no appreciable psychiatric risk. However when children who have been exposed to chronic stress, or several concurrent stresses, must deal with family discord, the adverse effects increase markedly. In addition, extrafamilial factors such as stresses and supports in other social institutions or networks, the quality of housing, neighborhoods, child care, the need for the mother to work, economic status, and geographic mobility will moderate or potentiate stresses associated with divorce (Colleta, 1978). Divorce can actually increase the probability of the occurrence of another stressor. This is most apparent in the stresses associated with the downward economic movement that frequently follows divorce and makes raising children and maintaining a household more difficult (e.g., Bane, 1976).

There has been little research on the long-term effects of divorce. In a national survey of adults whose parents divorced when they were children, Kulka and Weingarten (1979) examined their psychological adjustment and the responses toward marital and parenting roles. That study compares the survey responses of two large and representative samples of the American adult population. The first survey was conducted in 1957; the second, in 1976. These two samples span the period of an unprecedented increase in the divorce rate. However, most of the adults surveyed in 1976 were children of divorce at a time when it was still a relatively unusual occurrence. (Thus, this study does not tell us about the long-term effects of divorce on children living in a more permissive social climate.) Kulka and Weingarten found some differences in children of divorce in 1957 and 1976, some of which may stem from changes in social values. In both samples, they have found some differences in adjustment between those adults whose parents divorced when they were children and those adults who grew up in intact homes. But, most important, Kulka and Weingarten report far fewer differences between adults from intact and divorced families of origin than might be expected, given the short-term, relatively high levels of distress discussed earlier. They find that being a child of divorce is related to some measures of adult psychological adjustment and to some responses to marital and parental roles, but that these relationships are relatively few in number and statistically small.

It must be noted, however, that it is extremely difficult to detect the long-term consequences of a single event. A year-long process of separation and divorce will absorb much of the lifetime and energy of a child of five who has few resources beyond the family. By the time that child has reached twenty-five, however, other crises, some more intense, some of longer duration, may well have occurred. Furthermore, many opportunities for health, growth and development may also have arisen. Thus, the Kulka and Weingarten research raises many general questions about the ways in which early experiences (what experiences? how early?) affect later life (what aspects of life? how much later?)

These are central conceptual and methodological issues in developmental psychology. How the effects of early experiences are maintained and incorporated as major themes in adult functioning, or recede in importance as time passes, are not well understood. It is likely that crises such as divorce can best be described as events that initiate a somewhat predictable and characteristic short-term sequence of problems (and possibilities); and that these, in turn, have both an independent effect on subsequent functioning and lead to new problems and possibilities. The divorce may begin a chain reaction, but it does not determine how it will reverberate. The child's personality, the social milieu, and subsequent events are factors that must be taken into account. But a sound understanding of this developmental sequence awaits the results of longitudinal studies that have yet to be conducted.

FUTURE DIRECTIONS

Several themes for needed research and improved methods emerge from this review. While many future efforts will of necessity build upon the studies reported here, others will break new ground and attempt to fill gaps in our knowledge that can no longer be ignored. Although no one can predict where major new insights will appear, it is both desirable and beneficial to try to anticipate them.

Traditionally, research on the family has been concerned with the effects of childrearing practices on the child, as illustrated by the work on moral development and sex-role socialization reported here. In most of this research, fathers have been ignored; but with increasing maternal employment and changing sex-role expectations, this is no longer the case. To some extent, the research question has been how well fathers can substitute for mothers, but there is growing recognition, noted in the discussion of maternal employment, that too much mothering may not benefit the child. Even in traditional intact families, fathers have a unique contribution to make to the social and emotional development of children (Lamb, forthcoming). In fact, researchers only recently have begun to examine the full complexity of socialization in families, to study the importance of siblings as well as parents, and to assess the child's own contribution to the socialization process. Several recent studies have documented how a child's response to parental behavior can reinforce undesirable patterns of interaction, thus creating a cycle that is difficult to interrupt (Maccoby and Martin, forthcoming). More research is needed to understand such complex patterns of interaction within families.

To some extent, the study of development in the context of systems of relationships has been stimulated by the growing number of children who live in nontraditional family arrangements, including communes and single-parent households. We can expect, for example, new research to explore how characteristics of relationships (mother to father, parents to sibling, sibling to sibling) influence a child's social and emotional development. Such findings would complement our knowledge of how *individuals* influence a child's development.

While research reported here reflects a growth in the knowledge of family and peer influences, researchers have just begun to examine how variations in a child's *social* environment influence development. In moving from family, to peer group, to school, to informal organizations—how are the child's conceptions of social life and the requisite social skills influenced? What is the special contribution of social relationships that develop in day-care facilities, schools, churches, sports activities, and neighborhoods? What is the role of culture and subculture in shaping these arrangements and their perception? What is the potential value of cross-age interactions and relationships among youth? There is some recent evidence, for example, that preschool children who are social isolates can become more socially active after involvement in play sessions with a child who is 16 months younger (Furman et al., 1979).

The perceptive reader will have noticed that while many of the studies discussed here have incorporated some consideration of emotions, none has directly addressed the nature of a child's emotional development. Specific emotions, such as fear and anger, have been studied at certain ages but rarely have researchers examined developmental changes in the expression and experience of emotions—not to mention their emerging role in prosocial behaviors, moral development, and motivation. There are healthy signs that this situation is changing, however.

The measurement of emotions through facial expression, for example, is being combined with other assessments of emotion such as heart rate and verbal description (e.g., Campos et al., 1975). Much of the recent work on empathy is developmental and has attempted to incorporate an increasing range of emotions. In psychology more generally, the role of emotions in a variety of behaviors is receiving increased research attention (see, for example, Zajonc, 1980). It is likely that in coming years the long overdue study of emotions in children will receive serious attention, reflecting its important contribution to human development. To some extent this work will be informed by the growing linkages between child psychiatry and developmental psychology (Selman and Yando, 1980). In fact, a significant trend in developmental research has been the increasing study of children with social and emotional disorders. This work will clearly benefit from a sharing of theories and observations between clinicians and researchers.

Of special importance to practitioners are the attempts to identify precursors and childhood determinants of emotional disorders. To do this, longitudinal studies are conducted with children who are at "high risk" for subsequent disorder because of some genetic or environmental condition (e.g., schizophrenic parents, early loss of a parent). These are expensive, time-consuming studies but some that were initiated several years ago are now beginning to bear fruit. A similar method is being used to study the "invulnerable child"—the child who remains competent despite being at high risk for a disorder. What are the factors that enable these children to develop normally or resist being damaged by stress and disadvantage? When the findings from this research are merged with those from the longitudinal studies of emotional development in normal children, we will have a fuller picture of developmental processes.

Some of the research reported, such as the studies on the effects of television, divorce, and maternal employment, has related directly to the impact of social change upon children's social and emotional development. Other efforts have focused more on the identification of basic developmental processes. Even in the latter types of research, findings can have important implications for social programs and policies. For example, research on attachment in infancy suggests some of the potential effects of prolonged separation from parents, whether due to death, divorce, hospitalization, or maternal employment. An understanding of the processes by which children acquire the capacities to delay gratification or be intrinsically motivated have important implications for job performance and worker satisfaction.

Like all good science, the research anticipated and advocated here and earlier in this report will be costly. Yet children are our most important resource. Knowledge about their development is important not only for its own sake, but for the promise it holds to maintain and improve mental health and the quality of family life.

NOTES

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2. This section draws heavily from a review article by Lois Hoffman (1979).

3. This section draws heavily and includes excerpts from review articles by Mavis Hetherington (1979) and Teresa Livitin (1979).

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FEDERAL AGENCY PERSPECTIVES: A FIVE-YEAR OUTLOOK

Introduction

The papers that follow present the combined perspectives of 22 Federal agencies on the relationships between science and technology and problems of national significance. The 11 papers included in this set of source materials for the *Five-Year Outlook* were produced by 11 task groups, each working within a particular substantive area corresponding generally to one of the budget function categories used by the Office of Management and Budget. The task groups consisted of representatives of those executive branch agencies that have major science- and technology-related missions and activities.

Each agency provided source materials to all of the task groups related to its areas of interest, and these contributions were integrated by a designated lead agency into a single paper covering that substantive area. As the agencies were encouraged to contribute to all functional areas in which they have programs, activities, or major interests, many provided inputs to functional areas in which their budgets are not normally reported. This procedure, also used in preparing portions of the third and fourth *Annual Science and Technology Reports*, was followed to provide as comprehensive a view as possible of the interacting perspectives of the various Federal science and technology agencies, even though it precluded the possibility of a one-to-one correspondence between the components of each functional area paper and the components of each Office of Management and Budget functional budget category.

In making their contributions, the Federal agencies were asked to provide both their perspectives on major problems, opportunities, and constraints related to science and technology and, where possible, their plans for alleviating those problems or constraints or for taking advantage of those opportunities. The agencies were asked to restrict their inputs to only major areas of concern; therefore, the papers do not cover all possible topic areas, nor do they review all relevant extant or planned Federal programs. The interested reader might consult the documents in the *Annual Science and Technology Report* series, which provide more specific descriptions of the range of Federal science and technology programs and activities, organized around the same functional areas as those used in this set of papers.

1 National Security*

HIGHLIGHTS

- It is imperative that the United States continue to increase its investment in science and technology to offset recent Soviet gains in military capabilities.
- The defense mission requires highly sophisticated electronic systems. Research on very high speed integrated circuits, ultrasmall electronics, electronic warfare, and embedded computer software technology will support that need.
- Artificial intelligence will be given greatly increased attention and, coupled with work on automation and robotics, can be expected to have an expanding role in military operations.
- Technologies for application to command, control, and communication systems will be explored. Emphasis will be placed on computer communications and distributed computer networks.
- The combat capability of tactical aircraft can be improved by new electronics technologies. Research in advanced propulsion systems will produce aircraft engines with increased durability and reliability.
- High-power space-based lasers, together with associated surveillance and command/control elements, have potential in the long term to provide for effective space defense. Particle beams offer an alternative but higher risk concept of directed energy for space defense.
- Advanced sensor systems and associated data analysis procedures will be applied to nuclear test verification. A marine seismic system will monitor the most seismically active regions for clandestine underground tests.
- High-technology weapons systems designed to overcome a quantitative superiority in an enemy's land combat forces are under development. They include Assault Breaker, Tank Breaker, indirect-fire technology, advanced cruise missile, and precision guided munitions systems.
- New materials technologies will have a major influence on the design and performance of future weapons and support systems. Carbon/carbon composites, metal-matrix composites, and rapid solidification technology are promising.
- Human behavioral factors are recognized as a critical element in ensuring the vigor of the Nation's defenses.

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* Participants in the task group developing this section included representatives of the following components of the Department of Defense: the Office of the Deputy Undersecretary of Defense for Research and Advanced Technology, the Defense Advanced Research Projects Agency, and the Departments of the Army, Navy, and Air Force. The Nuclear Regulatory Commission and the National Aeronautics and Space Administration also provided information on their defense-related activities.

Areas of concern are improvements in work force effectiveness, education and training, human-computer interactions, and human factors engineering.

- Modern weapons systems and combat doctrine may strain the human organism's capability and adaptability. Health research will focus on disease control, defenses against biological warfare, combat casualty care, and prevention of health hazards.

INTRODUCTION

In recent years, our national security has become increasingly dependent upon maintaining U.S. superiority in broad areas of science and technology. The science and technology programs of the Department of Defense (DOD), materially augmented by those of other Federal agencies and the private sector, provide the foundation for highly effective armed forces equipped with technologically superior weapons systems. Given the substantial quantitative and qualitative advances in the military capabilities of the Soviet Union and its allies in the last 15 years, it is imperative that we continue to increase our investment in science and technology to offset the Soviet gains.

Dollar cost estimates for Soviet military research, development, test, and evaluation (RDT&E) expenditures indicate that they have exceeded annual U.S. expenditures during each of the past 10 years, leading to an aggregate gap of about $90 billion (in 1982 dollars) and a military RDT&E program that is now about twice as large as ours. A clear indication of their commitment to defense technology is the trend toward increasing the share of Soviet military outlays devoted to RDT&E.

Despite the imbalance in RDT&E outlays, we have maintained our leadership in most of the basic technologies critical to defense, in large measure because of our commercial technology edge and the substantial momentum in defense technology derived from the lead we built up during the 1960s. But we are losing our lead in certain key technologies, including electro-optical sensors, guidance and navigation, hydro-acoustic technology, optics, and propulsion.

We are also concerned about the momentum of the Soviet research and development program. We can identify major new Soviet systems in various stages of test and evaluation and expect the Soviets to develop more new and modified systems during this decade. The scale of development makes it quite clear that the Soviet R&D program has had high-priority access to funds, to trained personnel, and to scarce materials. Because of the intense and persistent Soviet commitment to defense technology, it will become much more difficult to maintain our technological advantage. When we consider the secrecy with which the Soviets conduct their activities, it is clear that in the 1980s we will be facing a significantly greater risk of both qualitative and quantitative deficiency than ever before.

ELECTRONICS

The defense mission requires highly sophisticated electronic systems capable of high-speed information processing, operation in hostile environments, resistance to jamming and interception, applicability across the total electromagnetic spectrum, and high reliability and maintainability. Diverse research and development programs in DOD and supporting agencies range from basic studies of electronic materials, through the way such materials behave in devices, to the design and construction of components, the combining of components into circuits, and, finally, the building of systems based on those circuits.

VERY HIGH SPEED INTEGRATED CIRCUITS (VHSIC)

The VHSIC program, begun in fiscal year 1980, is a 6-year, triservice/industry/university development program designed to make a substantial step forward in integrated circuit performance and production capabilities for future military needs. VHSIC is aimed at establishing a new plateau of performance orders of magnitude above what can be accomplished with today's large scale and very large scale integrated (VLSI) circuit technology. A tenfold reduction in size, weight, power consumption, and failure rate, with accompanying savings in both initial and life-cycle costs of military computer processing systems, is envisioned. The requirement is for small subassemblies to provide 100 times the processing throughput of present integrated circuits for real-time data processing applications in surveillance, electronic warfare, advanced weapons systems, and command/control/communications. New or improved chip architecture will be developed to permit chip design at an affordable cost, with minimum customization to reduce supply and logistic costs. The program will provide for the commercial availability of submicron lithography equipment and an industrial capability for producing VHSI circuits.

The VHSIC program should accelerate the advancement of microcircuit technology by at least 5 years, firmly reestablishing our national leadership in that rapidly changing field. It will also ensure the industrial capability and sources for the electronics required by the next generation of computers, missiles, radars, and intelligence processing centers. The need for a VHSIC program grew out of the realization that the military portion of the integrated circuit market had diminished to less than 10 percent of that market, and the best products of the industry were being applied to the consumer, business, and industrial sectors of the economy. Because military systems require capabilities that are different from those of civilian markets, the VHSIC program was designed to encourage the electronics industry to seek the revolutionary advances required for defense missions while providing the opportunity for technological leadership in high-volume markets. For the semiconductor industry, VHSIC is a substantial program, increasing the level of DOD R&D support in integrated circuit technology to four times what DOD's support has been in recent years. Thus, VHSIC seeks to extend the existing industry technology and to gain considerable leverage through its investment.

To encourage rapid diffusion of VHSIC technology throughout the U.S. semiconductor industry, second-sourcing clauses are incorporated in VHSIC contracts to require contractors to enter into licensing arrangements for those parts of their VHSIC manufacturing system (including software) developed under the program.

ULTRASMALL ELECTRONICS RESEARCH (USER)

DOD has recently initiated an important, very long range effort in ultrasmall electronics research (USER), which is intended to advance electronics technology substantially, beyond even the goals of the VHSIC program. Whereas the VHSIC program may be regarded as a near-term, accelerated evolution that intensively exploits current silicon device technology, the USER program aims at revolutionary changes, 10-20 years ahead, that will depend upon entirely new concepts and materials. USER will deal mainly with the fundamental physics, chemistry, metallurgy, and transport of charge in highly constrained geometrical structures which may be used in future (beyond VHSIC) generations of highly complex integrated circuits. The conventional electron device models no longer apply when dimensions shrink below 200 nanometers (2,000 angstroms), and new quantum mechanical concepts for electron transport will have to be developed. Problems inherent to present size structures may diminish in consequence while others, previously ignored, may begin to dominate device operation.

With the advent of high resolution electron, X-ray, molecular, and ion beam lithographic techniques, ultrasmall devices can be envisioned in which individual features might well be fabricated on the molecular scale of dimensions (that is, 10-20 nanometers). Some structures that have been proposed are so small that the bulk properties of the host semiconductor material may be significantly less important than size-related effects. Such effects as tunneling, size-quantization, long-range order, and fluctuation phenomena produced by interactions with neighboring structures will become important. In such devices, temporal and spatial scales will become so short, and the electric fields so large, that the physical concepts used in analysis of today's semiclassical device physics would be inappropriate and, indeed, might be misleading. Moreover, the new physical properties could lead to radically new electronic device structures in which the individual device might assume a variety of functions that depend on the influence of neighboring devices. A direct result of the ultraminiaturization of devices and the ongoing development of VLSI or VHSI circuits will be a rapid growth in the complexity of circuits and the generation of new design and fabrication problems, with the usual growth in costs. While VHSIC will address some of those problems, it is clear that in the submicron region of electronics, other complexities arising from physical processes operating in closely spaced devices will require that USER develop new concepts for circuit design, computer architecture, and circuit fabrication.

USER has been called one of the last remaining frontiers of solid-state electronics, where the new fundamental unit is an aggregate or array of molecules or atoms. While the research program has highly speculative aspects, the potential payoff could greatly bolster U.S. preeminence in both military and civilian applications of electronics in the decades ahead.

ELECTRONIC WARFARE (EW)

Electronic warfare is concerned with exploiting the electromagnetic spectrum for friendly use and denying it to hostile users. The DOD technology program in EW is divided into radio frequency (RF), electro-optic (EO), and acoustic EW, since the techniques of energy generation and detection, the effects of the medium on propagation of the energy, and the measurement of target and background signatures are unique to each spectral region. In each region, EW provides methods of countering surveillance, communications, and weapons. The DOD science and technology program in EW embraces the following functional areas:

- *Detection and location*—which includes improved receivers, warning systems, and direction-finding techniques to operate in a very dense signal environment.
- *Jamming and deception*—which includes programmable jammers, expendable decoys, and countermeasures against radars and missile seekers.
- *Signal reduction and obscuration*—which includes reduction of aircraft visibility, infrared signatures, smoke, obscurants, and improved chaff.
- *Counter-countermeasures*—which cover spread spectrum techniques, frequency diversity, and adaptive antenna methods.
- *Exploitation and simulation*—which includes the evaluation of the vulnerabilities of hostile weapons systems to countermeasures.

Currently, we are developing jointly with Canada a passive infrared search and track (IRST) system designed to detect antiship missiles. The system provides complete azimuth coverage and passive surveillance of airborne and surface targets. In both land and sea tests, IRST has demonstrated a high probability of designating missiles in a heavy clutter environment, and the Navy is studying its needs and evaluating the type and number of ships that should receive the IRST system. Other recent accomplishments include successes in signal suppression through the use of radar and infrared absorbing chaff against radiation spanning the entire spectrum from far infrared to nearly microwave wavelength. Considerable effort has also been devoted to developing systems that detect electro-optical threats, and progress has been made in developing detection systems that indicate whether an aircraft or tank is being designated.

There have been two major shifts in emphasis in EW technology in the recent past. First, counter-countermeasure techniques have received increased emphasis in response to the severe and increasing EW threat. That is due to the perceived weakness of our electronic systems in an EW environment and the recognition of the magnitude and sophistication of the Soviet threat. Second, the proliferation and increased effectiveness of electro-optical weapons systems has caused a shift in emphasis from RF to EO technology. In particular, there has been a rapid growth in countermeasures against such EO weapons as missiles that employ infrared homing, track by video contrast, and seek laser-designated targets. Furthermore, air defenses are using EO systems to back up radar-directed fire control.

EMBEDDED COMPUTER SOFTWARE TECHNOLOGY

Because advances in software technology have not kept pace with the dramatic advances in computer hardware technology, the DOD has recently begun a concerted attack on software problems, with special emphasis on a few high payoff projects. The urgency of the software problem derives chiefly from the following factors:

- Software continues to be an increasingly important and expensive component of military systems, with estimates of DOD-embedded computer software costs now running as high as $5 billion per year. Nearly 70 to 80 percent of the cost goes for support and evolution of software after initial deployment.
- Advances in computer hardware technology are altering computer system characteristics and expanding expectations for military systems so rapidly that most existing software tools will be of limited use in solving the critical software problems of the mid-1980s.
- DOD's specialized software needs are not shared with most commercial and industrial applications of computers. They include requirements for automatic error recovery and fail-safe execution, simultaneous control of a variety of sensors and activators, critical real-time constraints, and extremely complex systems that are continuously undergoing modification.
- The approaching completion of the Ada standardized programming language effort provides an opportunity for coordinated development of generic software, significantly reduced duplication of DOD software support environments, and greater interoperability among military software development and support environments.

The software technology program has two major parts. The first is aimed at the short-term problems of realizing the potential benefits offered by the Ada common language effort, which include more effective use of existing software technology, elimination of duplication in developing and maintaining widely used software products, and interoperability among the tools and aids used in the development and evolution of embedded systems software. The second part of the program will be a longer term effort to greatly improve the effectiveness of automated software technology for military systems and to complement the computer hardware of the mid-1980s. It will pursue tasks with high potential and will emphasize responsiveness, timeliness, robustness, and reduction of the indirect costs of software. The specific objective is to reduce software life-cycle costs for embedded computer systems through automated software technology.

Progress along any one of several fronts would have significant impact. For example, a factor of 20 difference has been observed in the productivity of individual programmers, and a factor of 6 improvement is common between the first and third implementation of similar systems by the same team. The ability to easily modify software without loss of reliability and efficiency would permit rapid responses to changing threats that might arise from the introduction of new target signatures or new countermeasures in a tactical situation. The ability to rapidly prototype systems for testing under realistic conditions would avoid those frequent situations in which a system is unused because critical characteristics were overlooked in its initial specification. Finally, it may be possible to automate many of the mechanical tasks and thereby free system designers to deal more effectively with the important problem of extending function and system effectiveness.

COMPUTER TECHNOLOGY: ARTIFICIAL INTELLIGENCE, AUTOMATION, AND ROBOTICS

The area of computer science known as artificial intelligence will be given greatly increased attention in the years ahead and, coupled with work on automation and robotics, can be expected to play an increasingly important role in solving military problems of engineering, management, logistics, reliability and maintainability, remote sensing, surveillance, and vehicle and weapons control.

A recently established DOD program is directed at developing "smart" computer systems with capabilities for mimicking man's capacities of commonsense reasoning and physical dexterity. It includes fundamental research on machine representation of world knowledge, language and speech understanding, computer vision and machine-controlled manipulators, and reasoning by analogy and inference. Directly tied to the artificial intelligence projects are efforts in systems automation and robotics.

A major research effort, scheduled to begin in fiscal year 1982, will investigate new automated systems using artificial intelligence techniques. The research will focus on methods both for representing knowledge and for reasoning with knowledge in computer systems, with special attention given to methods for knowledge representation and reasoning that are independent of the particular domain of knowledge, and to methods that are specialized for such relevant knowledge domains as image understanding. Other facets of the research will examine issues involved in developing large artificial intelligence systems using distributed computer architectures. The studies in systems automation will establish the foundation for a new generation of sophisticated, intelligent military systems that will provide new capabilities and ease manpower needs. Those new systems will range from "expert consultants" to autonomous systems. The "expert consultant" systems will assist their users in such tasks as planning and scheduling operations and diagnosing and repairing complex mechanical systems. Autonomous systems will be capable of commanding, controlling, and conducting military operations and will possess a capability to sense, think, and act.

Closely associated is the DOD work in robotics, which exemplifies the type of fledgling technology that DOD needs and is ready and anxious to support. The use of robotics in industry is driven primarily by the need for flexible, low-cost, high-productivity automation. American industry has some 2,000 robots at work today, compared to 13,000 in Japan. The Society of Manufacturing Engineers predicts that, by 1995, 50 percent of automobile assembly will be done by automated machines and robots. DOD has all the cost/productivity/morale problems of industry, plus a few special problems of its own. Not only must DOD manufacture systems, but it must support and maintain those systems across a far-flung theater of operations, frequently in hostile operating environments, using a largely unskilled labor force with a high turnover rate. Thus, the need for intelligent, flexible automation (robots) is obvious.

Currently, all three DOD services are tackling the problem of production, the simplest starting point. The Air Force Integrated Computer-Aided Manufacture (ICAM) project is addressing aircraft manufacture. The Army is using industrial robots for benching operations and loading of numerically controlled machines for cannon and breach manufacture and for automated munitions handling.

In the near future, the use of robots in DOD systems manufacturing will increase in parallel with industry. Maintenance and repair departments at intermediate- and depot-level activities will begin to use robots as the technology matures to the point where robots can deal with the complications and variations associated with such work. An example is the Navy Robotic Deriveter, which is scheduled for a 2-year development program beginning in fiscal year 1981. Deriveting is necessary because salt water causes corrosion damage to airframes which must then be dismantled for repair. That time-consuming, tedious, repetitive task will be done by a robot using an ultrasonic sensor and commonsense artificial intelligence to "learn" the rivet pattern, rapidly inspect the airframe structure around each rivet, and remove the rivets. The system will be able to handle several sizes of rivets in a variety of patterns on many different aircraft types.

In the longer term, robots will be developed for DOD field uses to assist combat and support forces. Field applications will place still greater requirements on robots to be flexible and intelligent and to have sensory capabilities. For example, it has been suggested that much of the maintenance on-board ship could be done more efficiently if each ship used a work-cell operated by intelligent robots to manufacture parts needed, rather than carrying vast numbers of seldom-used spares.

COMMAND, CONTROL, AND COMMUNICATION

The DOD program in command, control, and communication (C^3) is attempting to develop advanced technology and system architectures to improve the Nation's ability to control its fighting forces around the world. Strategic and theater C^3 effectiveness in the 1980s and beyond will depend upon recent advances in information processing that allow reliable and rapid manipulation and movement of information across large distances. Strategic C^3 systems must be able to survive in combat and be highly dependable as links between the command structure, strategic reserve forces, and troops in the field; communications response time is also a critical factor. In pursuing the development and demonstration of C^3 technology in a broad strategic and tactical systems context, experts are exploring computer communications technologies for application to both individual C^3 networks and internetwork systems. Emphasis on distributed computer network research should result in improved combat survivability and reliability and should help meet geographic distribution requirements. Where appropriate, testbeds are used to evaluate the impact of new digital processing techniques in realistic military operational settings.

COMPUTER COMMUNICATIONS

Advanced packet communications techniques and a powerful experimental internetwork are being developed to provide local, regional, and long-band computer communications via ground radio transmissions, terrestrial circuits, and satellites. A multistation packet radio network with distributed control functions was successfully installed at Fort Bragg, North Carolina, and connected to ARPANET. It is supporting a joint Defense Advanced Research Projects Agency (DARPA)/U.S. Army data distribution testbed, and substantial improvement in network communications survivability is expected.

SECURE DISTRIBUTED INFORMATION SYSTEMS

DOD is also developing the technology for securing classified information processed or stored in computer and communication networks. Basic research in distributed computer systems is addressing the military need for geographically dispersed multicomputer command and control systems. An end-to-end network encryption system was recently demonstrated, and DOD is using the concepts in securing the experimental testbeds described below. In fiscal year 1981, new initiatives were begun on the design of secure distributed transition systems in which several security levels must be handled concurrently.

DOD is using a number of experimental testbeds to evaluate new information-processing technologies in realistic military environments. The Advanced Command and Control Architecture Testbed (ACCAT) is a DARPA/U.S. Navy effort to develop, demonstrate, and evaluate innovative command and control architectures. A mobile access terminal to support ACCAT access from Navy ships is under development, and experimentation will expand to include surveillance and combat direction functions. The DARPA/U.S. Army Data Distribution Testbed is a series of "hands-on" C^3 experiments being conducted by the XVIII Airborne Corps at Fort Bragg to evaluate the use of distributed systems technology and automatic data processing on the battlefield. A third major testbed activity is a strategic C^3 experiment being undertaken jointly by DARPA, the Defense Communication Agency (DCA), and the Air Force Strategic Air Command (SAC). That testbed is intended to demonstrate air-to-ground packet radio communications and the use of distributed systems for survival and reconstitution of the SAC command/control capability during and after a major attack on the United States.

AERONAUTICAL TECHNOLOGY

AIRCRAFT TECHNOLOGY

The DOD science and technology program incorporates a major thrust to integrate electronics and the airframe in order to achieve a significant improvement in the combat capability of tactical aircraft. It will soon be possible to "fly-by-wire" with smaller control surfaces on more highly maneuverable aircraft; to maximize aircraft performance by automatically changing in flight the shape of such key aircraft components as wing sweep, airfoil camber, and engine inlets; to provide independent 6-degrees-of-freedom control to increase agility and minimize weapon delivery errors; and to integrate the flight, fire control, and navigation systems. Those advances will provide task-tailored handling qualities. Fire control information will be used to automatically or semiautomatically assist the pilot in maneuvering the aircraft into the proper launch envelope for a specific weapon. Additionally, the new control concepts will provide the capability to conduct a maneuvering approach to launch for air-to-ground weapons, thereby increasing survivability against ground defenses. Recent simulator studies have shown that application of those concepts results in a 2-to-1 increase in weapon delivery accuracy for both air-to-air and air-to-surface weapons and up to a 10-to-1 increase in survivability during air-to-surface weapon delivery, depending on the ground defense.

Major advances in V/STOL technology were accomplished in 1980 with the demonstration of the XV-15 tilt rotor aircraft to the design limit speed of 300 knots. The tests, performed under joint sponsorship of the Army, Navy, and the National Aeronautics and Space Administration (NASA), have demonstrated the feasibility and practicality of the tilt rotor concept. Testing of the concept, which provides helicopter-like hover characteristics and the ability to fly efficiently at speeds up to 400 knots, will continue through fiscal year 1982.

AIRCRAFT PROPULSION

The objective of the aircraft propulsion program is to have proven technology ready for the next prototype or engineering development program. The program demonstrates propulsion advancements that can be applied to future systems.

Recent investigations of the aircraft engine development programs have concluded that, during the early research and development phases of the program, additional efforts need to be placed on durability and reliability aspects. The Congress has recognized that need and provided additional funds for more hardware and testing of advanced components and advanced technology demonstrator engines. In addition, the technology program is being reoriented to stress reliability and maintainability.

The increasing costs of propulsion systems and the supporting costs after they are placed in operation have become major concerns. Since a major cost driver is the number of parts in a propulsion system, current efforts are aimed at reducing the number of engine compressor stages by improving individual component performance. A major effort is being made in the Advanced Turbine Engine Gas Generator (ATEGG) program to increase the structural testing of promising new turbine engine concepts. Successful completion of the tests should provide a base for better and more timely transition of advanced technologies to engines.

A triservice working group has been formed to define an overall plan to develop and demonstrate small engine technology in the 1 to 7 pound per second airflow class. Such engines are applicable to auxiliary power units, light helicopters, light fixed-wing aircraft, and cruise missiles, all of which are or will be widely used by U.S. forces.

SPACE DEFENSE AND SURVEILLANCE

The rapid exploitation of space as a medium for important military functions raises the potential for hostile acts against U.S. space assets and presents a requirement for effective space defense and surveillance.

LASERS

Recent DOD advances in space laser technology create opportunities for high-energy laser weapons. While very long lethal ranges and propagation at the speed of light make lasers uniquely capable for such applications, improvements by several orders of magnitude in critical performance factors would be required before weapons applications would be possible. The current DOD effort is intended to develop the basic technology to apply those improvements to critical laser design parameters and to advances in system performance.

In the past year, there has been substantial progress toward establishing the technology base for chemical laser weapons. Scale system testing has verified that the high fuel efficiency obtained previously with subscale systems also applies to higher power laser devices. In addition, researchers have developed unconventional concepts that equal, and in some cases exceed, the performance of existing devices. The high fuel efficiency and decreased weight attainable when the new concepts are applied could translate into a space laser weapons system of lighter weight or with more fuel storage capacity, if scaling continues to hold for very high power laser devices.

To support long-term laser applications, DOD initiated a ground-based laser radar program that utilizes a high-power laser to track U.S. space objects. The system has successfully tracked high-altitude targets with exceptional accuracy. Identical techniques can be used for fine tracking applications at extremely long range, thus enhancing the potential of high-payoff, very large chemical lasers for ground-based applications.

CHARGED PARTICLE BEAMS

The charged particle beam program is intended to demonstrate the feasibility of stable, predictable propagation of high-power relativistic electron beams in the atmosphere over distances of military interest. The essential tool for investigating atmospheric electron beam propagation is an Advanced Test Accelerator (ATA), now under construction at Lawrence Livermore Laboratory. The Experimental Test Accelerator (ETA), which will serve as the front end for the ATA, was completed recently, and experiments will be performed to extend previous low-energy propagation data. When completed at the end of fiscal year 1982, ATA may provide the essential scientific data required by DOD to begin planning preprototype weapon developments.

SENSORS

The principal emphasis in the space surveillance program has been on advanced visible and infrared detector arrays. The enhanced capabilities of such devices permit a variety of surveillance and battle management missions not possible previously. HI-CAMP (high resolution calibrated airborne measurement program), an advanced, high resolution infrared sensor, has been installed in a NASA U-2 aircraft to collect measurements of Earth background and tactical targets. The program is the first field demonstration of mosaic focal plane technology with large numbers of detectors.

Advanced detector array production for the DARPA TEAL RUBY experiment, the first on-orbit demonstration of advanced detector technology, will provide a target/background signature data base to support the design of future operational systems. The sensor is scheduled for delivery to the U.S. Air Force for integration with the P80-1 spacecraft for planned shuttle launch in the early to mid-1980s.

The DARPA HALO (high altitude, large optics) program is developing an advanced technology base in large focal plane arrays, spectral filters, substantial signal processing, optics, and detector cooling. A space experiment, Mini-HALO, will demonstrate HALO technology using the sensor to evaluate the feasibility of performing various strategic surveillance missions from space.

NUCLEAR TEST VERIFICATION

DOD research in nuclear arms test verification is intended to provide a wider range of sensor options and greater assurance of detection and identification of nuclear tests. The effort is strongly involved in the development of advanced sensor systems and associated data analysis procedures. With recent advances in characterization of seismic sources and wave propagation modeling, and the completion of a worldwide network of high-quality digital monitoring stations, it is possible to develop source identification procedures based on physical and geometric properties. Such techniques could be applied to areas where prior signal recording is lacking. The current effort includes synthesizing existing models into a processing technique for recorded digital data and designing experiments to validate the technique.

A marine seismic system (MSS) demonstration program will offer the possibility of monitoring, unobtrusively and at close distances, the most seismically active regions for clandestine underground tests. The MSS will significantly enhance global monitoring of underground/underwater testing. The MSS consists of a high-quality, three-component borehole seismometer and associated signal conditioning electronics suitable for long-term placement in the deep ocean floor. The seismometers will be placed in boreholes drilled into firm bedrock to achieve the maximum isolation from background noise, and data will be transferred to a central analysis center either by bottom cable or by satellite link. The program will demonstrate the feasibility of installing and operating the most advanced seismic detector in a borehole in the deep (5.6 km) ocean floor and will define the seismic detection capabilities of such a system. The MSS incorporates advanced sensor technology developed under a parallel DARPA research program. Application of the seismic data to detection, location, and identification of underground explosions will depend on analysis techniques developed under ongoing DARPA programs in seismic source and signal propagation theory and advanced data processing.

The MSS program was initiated late in fiscal year 1979, and the design for the system was completed at the end of fiscal year 1980. Techniques and specialized equipment required for placing the instrument in boreholes in the ocean floor using the drillship *Glomar Challenger* have been completed. An at-sea test conducted in the mid-Atlantic in 1981 will verify operation of the equipment and gather initial data on seismic noise reduction. The sensor, with associated electronics required for data acquisition and storage, will be developed by early 1982, and deployment of the system is scheduled for the summer of 1982. Full system communications will be added in 1983.

WEAPONS

A major objective of the Department of Defense is the strengthening of conventional forces, particularly in Central Europe where the Warsaw Pact forces dramatically outnumber NATO forces. Current Warsaw Pact military doctrine stresses the offensive and calls for arranging its forces in echelon to generate and sustain attack momentum along major axes of advance. The following are examples of new high-technology weapons systems designed to increase the ability of friendly forces to overcome a quantitative superiority in the enemy's land combat forces by effectively striking and weakening the exploitation of second-echelon forces at long range, before they can have a major influence on the outcome of the battle.

ASSAULT BREAKER

A joint DARPA/Army/Air Force program has been initiated to develop and demonstrate the integration of several advanced technologies that will provide a nonnuclear, standoff weapons system capable of engaging and destroying sizable armored forces beyond the main battle area. The proposed system, designated Assault Breaker, consists of three major elements: a target acquisition and weapon bus guidance radar (PAVE MOVER), a submunition-carrying missile or aircraft, and terminally guided submunitions (TGSMs). Advanced radar modulation and signal processing techniques are being developed for the PAVE MOVER radar to detect and track armored targets and to provide guidance for an assortment of weapons that may be used against them. Advanced submunitions capable of autonomous lock-on and guidance to the individual armored vehicles are being developed.

The Assault Breaker program will reach three major milestones during fiscal year 1981. Flight testing of the PAVE MOVER radars was begun during the first quarter. During the second quarter, free-flight tests of the surface-to-surface weapons will proceed at White Sands Missile Range. The tests will attack armored targets located at considerable standoff ranges from the launch point. Finally, integrated tests with PAVE MOVER radar guidance, Patriot and Lance booster missiles, and end-game TGSMs will occur during the third and fourth quarters. The radar and surface-to-surface programs will then be transferred to Air Force and Army management for engineering development during fiscal year 1982.

TANK BREAKER

The Tank Breaker program aims at providing advanced technology alternatives for the next-generation U.S. Army DRAGON missile to permit a lightweight, fire-

and-forget, lock-on-before-launch, shoulder-fired missile system to penetrate current and next-generation enemy tanks. Tank Breaker is a combination of advanced missile and target-sensing techniques; for example, it is the first tactical seeker application of focal plane infrared detector technology. The first quarter of fiscal year 1981 saw captive-flight testing of an imaging focal plane array seeker at Redstone Arsenal, Alabama. Wind-tunnel testing of the missile airframe and slug testing of the shoulder launcher will be carried out.

ADVANCED INDIRECT-FIRE TECHNOLOGY

A new effort to develop a next generation of artillery capable of interdicting armor beyond the line of sight is under way. The weapon will utilize "smart" sensors capable of autonomous terminal homing. DARPA and the Army are cooperating in a program that incorporates a tube-launched ram-jet projectile for extended range and terminal infrared homing. Seeker field trials and projectile firings are scheduled during fiscal year 1981.

ADVANCED CRUISE MISSILE

One of DOD's major thrusts for the next few years is the development of the advanced cruise missile. Current research emphasizes the engine, configuration, detection technology, and autonomous terminal homing. Achievement of extended range will improve carrier aircraft survivability, flexible routing, and ability to reach more targets. Scientists are developing the components for two advanced engines that offer significant improvements in thrust-specific fuel consumption over the current F-107 cruise missile engine. A full-scale engine validation program will start in mid-1981. The advanced cruise missile configuration project is focused on improving survivability and the range/payload product. A joint DARPA/Air Force validation phase, recently begun, could lead to a second-generation cruise missile with an initial operational capability as early as 1987. The first phase of the cruise missile detection technology project will develop techniques needed for low-altitude detection of small-signature vehicles using field-measurement data. The remaining two programs support cruise missiles using a conventional warhead. The autonomous terminal homing (ATH) project is developing an adverse-weather sensor and scene-matching algorithms to achieve a small guidance error against selected fixed targets. The near-term ATH technique will utilize a forward-looking infrared sensor.

PRECISION GUIDED MUNITIONS WITH ADVERSE WEATHER CAPABILITY

Precision guided munitions (PGMs) developed by DOD in recent years are missiles or gun projectiles capable of searching out such critical targets as tanks among all the clutter of a battlefield. Although PGMs that perform well in fair visibility are already under development, the next generation must provide the capability to perform at night and in adverse weather. Consequently, DOD will continue to emphasize the development of PGMs that will not suffer degraded performance in adverse weather or under conditions involving target obscuration by smoke, dust, or fog. A strapdown ring laser gyro (RLG) inertial guidance system has recently demonstrated accurate midcourse guidance for tactical missiles, and in the coming year it will compete with other low-cost inertial guidance systems to determine if lower costs can be obtained without sacrificing midcourse accuracy.

A concentrated effort on target signature characterization for millimeter wave (MMW) seekers is now moving forward. A cooperative program with Germany has just been completed in which infrared and millimeter wave measurements were made on armor and such other high-value targets as bridges, POL sites, and dams. During the coming year, data will be reduced and analyzed in a search for target-unique characteristics that will allow target acquisition when signal processing algorithms are employed.

Capitalizing on recent technical advances in solid-state electronics technology, the armed services have joined in an effort to demonstrate cost-effective adverse weather seekers against land and sea targets. Both synthetic aperture radar and millimeter wave seekers will be evaluated, beginning with a captive flight test demonstration in fiscal years 1981 and 1982 and culminating in a free-flight demonstration in fiscal year 1983.

NEW MATERIALS TECHNOLOGIES

Over the years, DOD's pioneering developments in advanced materials have led to vastly improved military capabilities as well as the creation of new U.S. industries. Fiberglass-reinforced plastics are now familiar almost everywhere. They are strong, tough, readily fabricated in complex shapes, and conservative of the materials required, since relatively little is wasted in fabrication. Virtually every U.S. and free world military aircraft, spacecraft, and ballistic missile in development or production contains fiber-reinforced plastic composite materials. Moreover, commercial and private aircraft now in development will use increasing amounts of those materials to improve efficiency and reduce fuel consumption. In effect, DOD, through early developments in its science and technology program, has created the rapidly growing, new worldwide industry of fiber-reinforced plastic composite materials.

Although that achievement has been formidable, the pace of advances in military technology has imposed even more rigorous demands on systems performance, and the quest for materials with still greater performance capabilities must be pursued vigorously in the years ahead. Superimposed on the requirements for improved physical behavior of materials is the growing specter of shortages of critical materials, particularly certain strategically important metals obtainable only from foreign sources. This adds urgency to the search for materials that not only offer performance improvements but may be developed from domestically available resources. The new materials technologies cited below illustrate promising new directions that may have a major influence on the design and performance of weapons and support systems in the years ahead.

CARBON/CARBON COMPOSITES

The development of carbon fiber-reinforced carbon (C/C) composite materials in DOD programs has led an increasing number of missile developers to consider using those materials to achieve significant performance gains, and a growing number of military and commercial aircraft now use C/C composite materials. Carbon fiber-reinforced plastics provide the high strength and the stiffness needed for such applications as aircraft wing and empennage components, helicopter blades, and other highly loaded structures. They are being used increasingly for such applications, where they can cut weights by 15–30 percent, greatly simplify design and construction, increase reliability, and reduce costs. Carbon fiber-reinforced carbon material is the most effective substance yet discovered for extremely high temperature applications such as ballistic missile reentry body nose tips and rocket nozzle throats. With further development, the materials are expected to become useful as high temperature turbine blades for cruise missile engines. The Navy and Air Force are investigating the viability of such materials in the hot sections of gas turbines, since extensive use of C/C composites for the gas turbine of a typical fighter aircraft carrying a 1,000-pound payload could lead to overall aircraft take-off gross weight reductions of about 30 percent. For a typical mission, the fuel consumption would decrease by about 14 percent.

In addition to the performance gains possible with C/C composites, their domestic availability and potential low cost could make them attractive alternatives to the high-cost gas turbine superalloys. Inasmuch as those superalloys contain substantial amounts of cobalt and chromium, for which the United States is almost totally dependent on imports, the development of C/C composites as alternatives could lessen U.S. dependence on foreign sources.

METAL-MATRIX COMPOSITES

Over the past few years, DOD has emphasized the development of fiber-reinforced metallic materials, referred to as metal-matrix composites (MMCs). A triservice/DARPA thrust program is proceeding on schedule toward development and application of MMCs for a variety of military applications, including helicopter transmission housings, portable bridging components, strategic missiles, mines and torpedoes, tactical missiles, airframe and gas turbine components, and satellite components.

In addition, MMC materials show promise for an ever-widening range of uses, including laser mirrors, lightweight gun mounts, submarine propellers, and radar antennae. One early result of the program is a fiber-reinforced lead grid material for submarine batteries that can lengthen the submarine battery replacement cycle from 5 to 10 years, thereby aligning it with the nuclear core replacement schedule and reducing maintenance costs appreciably.

In addition, trade-off studies indicate that extensive use of MMCs as structural components of a typical supersonic cruise missile could lead to a weight reduction of about one third. The development of C/C materials for gas turbine application, as described in the previous section, could alone lead to an overall weight reduction for the same typical supersonic cruise missile of about 50 percent. When both the MMC and the C/C technologies are additively applied, the weight of a typical missile could be reduced by about two thirds. Such weight reductions would make possible range extension (leading to improved survivability standoff distances) and/or more missiles per aircraft.

Another significant consequence is the potential substitution of MMCs for such critical materials as chromium, cobalt, titanium, and beryllium. For example, it has been determined that MMCs made of high-modulus graphite fiber-reinforced magnesium alloy exhibit stiffness, strength, and dimensional stability equivalent or superior to beryllium at the same weight. Eventually, a new industry may emerge that someday will rival that based on fiber-reinforced plastic composite materials.

RAPID SOLIDIFICATION TECHNOLOGY

In fiscal year 1982, DOD will move vigorously into the area of rapid solidification technology (RST). The objective is to produce high-quality starting materials for new families of aluminum and titanium alloys and superalloys. The current modest investments have demonstrated sufficient promise and maturity to justify a major, long-term, financial commitment by DOD to accelerate the development of those new materials. Moreover, RST has demonstrated the potential for producing superior superalloys with only minor amounts of critical or scarce materials.

Rapid solidification technology involves solidifying metals and alloys from a molten state at such a fast rate (greater than 100,000° per second) that their desirable characteristics are dramatically enhanced. Through the rapid solidification, the usual weakness in metals due to segregated and agglomerated impurities and undesirable compounds can be avoided. RST can be used on almost any alloy and yields a product that is homogeneous beyond any known observation. Additionally, the solubility of one metal in another is usually increased to the point where never-before-possible alloys can be made. The combination of those two advantages has led to recently discovered alloys with superior high-temperature strength, vastly improved corrosion resistance, and increased lifetime. For example, one new superalloy can run 100° hotter in jet engines, thereby offering the design flexibility of either a 15 percent thrust increase or a dramatic reduction in fuel consumption. A new aluminum alloy is 30 percent lighter for aircraft construction. In the future such new alloys could enable airplanes either to carry 30 percent more payload or to decrease fuel consumption. A new iron-aluminum alloy is more corrosion-resistant than stainless steel and does not use scarce chromium. These and other discoveries lead us to believe that Department of Defense capabilities could be importantly affected by RST.

The first application of the advanced materials could be in component improvement programs (for instance the F–100 engine in the F–15 and F–16, and the F–404 engine in the F–18). Those engines are based on technology that is more than 10 years old. While the constraints of the existing engine/aircraft designs limit engine performance, advanced RST materials could provide substantial improvements (e.g., a factor of three) in engine lifetime by the late 1980s. DOD's first demonstration of RST superalloys in actual test engines is scheduled for fiscal year 1984/1985. Application in an advanced demonstrator engine program (fiscal year 1985/1986), such as a Multiple Application Core Engine (MACE), would allow for exploitation in a number of production engines reaching operational capability early in the 1990s. Such engines would power growth versions of present aircraft as well as future advanced aircraft (tactical fighter, V/STOL, and advanced transport).

The DOD program will involve basic research, exploratory development, specific technology demonstrations, and manufacturing technology efforts which will be conducted at university, industrial, and government laboratories. The technology emerging will provide major economic benefits to transportation, space, and energy systems, and will strengthen the U.S. commercial manufacturing base in general. While both U.S. and foreign industry have reacted aggressively to the emerging technology, the capital investment needed by U.S. materials suppliers to develop mill-form products will only come from substantial involvement of the U.S. Government. Furthermore, an adequate data base derived from well-characterized products will be required to establish designers' confidence in RST materials. Much of the production scaleup and property characterization will be supported by industry if significant market incentives can be defined through demonstrated applications.

Other benefits can accrue from the easier manufacturing and increased durability of RST products. In the United States we lose $200 billion per year as a result of three aspects of materials degradation: corrosion, wear, and fatigue. If corrosion-resistant RST alloys were in place today, sizable savings would be realized. Machine replacement costs could be greatly affected if future metal systems were fabricated by RST. Additionally, bearings can run hotter and longer, new prostheses and implants will be possible, bridges can be made stronger, better petrochemical processing alloys are possible, and our dependence on such imported strategic metals as cobalt and chromium can be significantly reduced. Clearly, aggressive pursuit of innovative RST technology can have a major impact on the overall U.S. productivity posture, while significantly increasing defense capabilities.

HUMAN RESOURCES

The arena in which the armed forces must function is becoming increasingly complex. Weapons systems are more sophisticated, the speed of battle has increased, and the demands on the individual are mounting. Even the pressures of changes in our social system during peacetime are being felt by the military, and the all-volunteer system presents special challenges. Moreover, in the next 10 to 20 years, the U.S. Armed Forces may face the problem of an insufficient supply of available young people, current recruitment and retention problems may continue, and the costs associated with a rapid turnover in personnel will be high. Although the resolution of those problems involves a broad range of issues beyond the realm of science and technology, it is clear that a critical element in ensuring the vigor of the Nation's defenses is the development of a strong base in the behavioral sciences. Areas of particular concern include improvements in work force effectiveness, education and training, human-computer interactions, and human factors engineering.

IMPROVING WORK FORCE EFFECTIVENESS

The assessment of individuals for selection, classification, training, and advancement is a problem common to industry, educators, government, and the military services. A significant opportunity for the future is offered by improvements in, and increased utilization of, computerized adaptive testing that appears to have both quantitative and qualitative improvements over older testing schemes. The application of modern test theory and adaptive testing techniques can result in tests more than 50 percent shorter than conventional tests and with higher levels of measurement precision. Adaptive achievement tests with half the number of items can be as valid as conventional tests, and multicontent achievement tests can be reduced drastically in length without decreasing measurement efficiency. The design of the tests, as well as the intervention of the computer, serves to decrease bias. Obvious constraints are the initial cost of implementation and large-scale test construction for many discipline areas.

EDUCATION AND TRAINING

Research in education and training concerns the acquisition and retention of complex skills. It is mainly driven by two factors. (1) It is costly to train people to operate and maintain high-technology weapons systems; the cost of the training equipment often approaches the cost of the weapons system itself, and the manpower to design, build, and conduct formal training programs is intensive. (2) Many skills needed for combat cannot be imparted using conventional techniques in a peacetime environment. Those skills tend to be associated with operations in a hostile zone where certain enemy weapons and tactics are encountered for the first time. The need to acquire such skills under combat conditions accounts for a large proportion of the high attrition experienced at the beginning of a war. Consequently, critical combat skills need to be identified, and learning principles and media concepts for teaching them in peacetime need to be developed. Major research thrusts include identifying complex skills, modeling learning processes, developing instructional systems, identifying and validating candidate training media, and assessing output performance.

Current and evolving computer technologies may be expected to influence profoundly the methods and effectiveness of personnel training. One result will be to make possible computer-based instruction systems capable of holding complicated conversations comparable to a Socratic dialogue about a subject. A few successful artificial intelligence systems provide a window into the future: the DENDRAL systems for physical chemistry, MYCIN for infectious disease diagnosis, and MACYMA for calculus and other types of symbolic mathematics all demonstrate the ability to answer questions in the same way an expert would answer them. By 1985, there will be several such instructional systems in daily use, and numerous efforts will be under way to expand the range of topics covered and the depth of understanding possessed by the systems.

Expert systems to help people perform specific tasks are much like instructional systems. In fact, the three systems listed above were actually developed to be expert assistants rather than teachers. DOD has an enormous need for such computer tools to maintain its complex weapons systems in a hostile environment and in the face of rapid personnel turnover. By 1985, DOD should have developed and demonstrated a knowledge representation scheme for aircraft maintenance data that can be provided at reasonable cost and that is suitable for training aircraft mechanics, providing a diagnostic aid for special problems, and printing needed hard copy maintenance documentation. Once that knowledge representation technology is demonstrated, it should be rapidly applied to a variety of other systems during the better half of the decade.

HUMAN-COMPUTER INTERACTION AND DECISIONMAKING

The human ability to accept, assimilate, and act upon large quantities of information in anything approaching real time is severely limited. When the information comes from a number of diverse sources (sensors), is based upon different physical principles (radar, sonar, intercept, visual), is received in various forms (sight, sound, data readout) with varying accuracies, and may be transmitted simultaneously, the magnitude of the problem increases dramatically. Further research will be required to extend work already accomplished in logic analysis. Work will also be necessary in all aspects of artificial intelligence or, as it might be termed, computer-aided decisionmaking. There continues to be a need for more and better algorithms—those capable of assisting in the real-time analysis of uncorrelated data. At present, too few people are trained in the area of logic, and the number of people knowledgeable in both human logic and mathematics is indeed small.

With those factors in mind, DOD has undertaken a major basic research effort aimed at enhancing the information-processing and decisionmaking capabilities of people working in demanding environments, through better understanding of interactions between human operators and computers. In today's defense missions, sophisticated sensor and communications systems can gather an overwhelming amount of information that is valuable or critical to the conduct of operations. While signal processing techniques aid in reducing noise and in transforming raw data into meaningful forms, better management of information must occur at the interface between machine presentation and human responses if we are to cope with the information load. Automation of more processing functions certainly can contribute to information handling, but even far into the future, effective and dependable system performance will still require effective human operators and decisionmakers. It is clear that solid basic research on human-computer interaction is needed to guide development of improved tactical capabilities.

Problems with the interface between machine presentation and human responses in military operational environments and systems include these: (1) dealing with potential information overload for operators and decisionmakers; (2) dealing with time-critical information; (3) deciding what information in a high-volume system to save or store; (4) finding optimal organization for different mixes of information; (5) dealing with data bases prone to undetected errors or missing data; (6) presenting information in an optimal way for such diverse functions as alerting for a critical event, monitoring for an infrequent failure, diagnosing a problem condition, or presenting alternative courses of action; (7) allocating appropriate tasks to machines, operators, and decisionmakers; and (8) providing requisite control/input interfaces and employing effective feedback to users with varied skill and knowledge about the computer system.

Because the research area outlined here is interdisciplinary and at the frontier of interaction between the behavioral and informational sciences, combined research in psychological sciences and computer sciences is clearly needed. Research specialties that will be essential elements in such interdisciplinary projects include human factors, artificial intelligence, psycholinguistics, decision analysis, communications theory, information management, information display, human information processing, human aptitudes, systems engineering, and management science.

HUMAN FACTORS ENGINEERING

Human factors engineering is concerned with human performance implications for the design of hardware. Objectives of research are to: (1) provide basic knowledge of those sensory, perceptual, cognitive, and response characteristics that underlie task performance capabilities; (2) translate task performance information into new ways for man to interface with his equipment; and (3) develop methods for assessing man's contributions to systems. Current research concentrates upon vision and visual perception characteristics, neurophysiological metrics (e.g., visual responses that indicate perceptual and cognitive processes), information-processing principles for man-computer interface design, decisionmaking in command and control, and methods for measuring workloads. Multidisciplinary research in physical, biological, and behavioral sciences will be needed to provide the knowledge upon which improved systems and hardware can be based.

HEALTH AND SURVIVAL OF COMBAT FORCES

To defend the national security worldwide, U.S. combat forces are expected to move quickly from continent to continent, from temperate zone to arctic to desert, from sea level to high altitude, and to perform their military functions on arrival. New weapons systems may require more in the way of physical and psychological demands on the human operator than he or she is able to give, and new combat doctrine may require a military unit to perform for prolonged periods of intense, continuous combat, straining the human organism's biological adaptability. Those factors affect the combat force's state of health as well as its performance ability. Consequently, the military services are increasingly concerned about protecting the fighting man on foot, at sea, or in the air from a myriad of stressors, ranging from extremes of climate, mechanical forces, toxic atmospheres, and fatigue to medical factors affected by the peculiarities of military social structure.

DISEASE CONTROL

In the coming years, special attention will have to be given to infectious disease. The deterioration in the worldwide capacity for disease control, engendered by both economic factors and increasing biological resistance of vectors and disease agents to control methods, makes infectious disease, especially tropical disease, of increased military concern. Infectious diseases noteworthy in this regard include malaria, dengue, plague, scrub typhus, leishmaniasis, hepatitis, Rift Valley fever, Lassa fever, diarrheal disease, schistosomiasis, and arbovirus infections. Historically, of course, disease has been the primary cause of man-days lost from combat and a major factor in many military campaigns. There is in the United States little or no civilian incentive to pursue prevention of such diseases as malaria that are not common in the general population. The U.S. industrial technology base needed for development of preventive vaccines against such diseases has eroded severely, so that the military requirements must be met by the military itself. Emerging genetic engineering techniques may improve the ability to rapidly develop and produce needed biologicals, and the application of rational methodology will permit more efficient development of drugs to meet specific needs. Similarly, the geographic epidemiology of militarily significant disease will be of increasing importance, since national strategic interests extend to areas that are sources of critical raw materials and petroleum. Any contingency plans for such areas must take into account the prevalence of diseases that could affect military operations.

BIOLOGICAL RESEARCH

Ongoing and anticipated technological advances in microbiology increase the level of threat from aggressor nations that might elect to engage in offensive biological warfare. To defend against that possibility, we must continue to maintain a broad and ever-advancing technological base. Military medical research should continue to emphasize the development and production of safe and effective immunizing agents against a growing list of organisms that might be used, including some with extreme virulence. Other research efforts will attempt to minimize the threat by improving prophylactic and therapeutic methods and by accelerating diagnostic capabilities. Emphasis in the next 5 years will include applications of research technology for use in the field. All efforts in military disease hazards technology will continue to be coordinated with the work of other Federal agencies and international organizations.

COMBAT CASUALTY CARE

Another critically important aspect of the health and survival of combat forces is combat casualty care. Rendering medical care under the adverse conditions imposed by combat and operational environments requires a highly complex and technically advanced medical system. Conceptually, the system of echeloned care used by U.S. forces has changed little since the Civil War. It has capitalized on technical advances, but now faces new (or renewed) problems imposed by changes in the nature, extent, and intensity of the modern battlefield. The development of improved conventional munitions means new kinds of wounds, with distributions dissimilar from experience in prior wars. Possible use of such unconventional weapons as chemical, nuclear, or directed energy devices raises the possibility of combined injury or new classes of combat injury. We must know more of the effects of those types of weapons to be ready to deal medically with them. The availability of resuscitative fluid in the field is one example of such an emerging problem. Research is currently centered on a freeze-preservation technique, shelf-life extenders for preserved blood, stroma-free hemoglobin for battlefield use, and the development of techniques for removing blood group determinants from whole blood, thus providing a "universal donor" blood on demand. New medical and surgical techniques (for example, microsurgery) may also improve the long-term prospects for the severely wounded, but means must be found to make such high-technology approaches available as far forward on the battle front as possible.

Advances in remote diagnostic capabilities and in computer aids may permit more sophisticated measures to be used on the battlefield. Although there are points of coincidence of combat care with civilian trauma care, and DOD research will be conducted in cooperation with civilian organizations, the military requirements differ in both kind and degree.

PREVENTION OF HEALTH HAZARDS

Research in health hazard prevention is driven by current and contemplated future battlefield requirements. Technological advances, the increasing complexity of weapons systems, and the development of new tactics, doctrine, and training requirements expose individual soldiers and crews to a variety of hazards that may impair their health, exceed physical or emotional tolerance limits, or degrade their performance capability. New developments have prompted a dramatic shift in research efforts to identify and minimize the adverse impacts of weapons systems, materiel, and training or working environments on health and performance effectiveness. The resulting research emphasis will continue and will expand to meet new medical requirements that stem from newly discovered health hazards or the need to comply with Federal, State, or local health regulations.

A prominent thrust in DOD efforts is directed at developing health hazard assessment and prevention technology for the toxic effects of the "dirty battlefield" and other military environments. Many new compounds unique to the military pose health risks in the processes of manufacture, storage, transport, handling, field use, and exposure to combustion products or contaminants. New weapons systems require complete assessment of the chemical environment of crew compartments. Combat vehicle crew compartments and individual protective clothing ensembles may pose substantial risks of heat exhaustion and heat stroke to the user. New air and ground combat vehicles require assessment of the medical and performance effects of vibration, noise, and impact. Low-frequency noise has recently been associated with high-frequency hearing loss. Pulmonary, auditory, and other effects of blast over-pressure require further study. Chronic low-level laser exposure has been associated with irreversible vision impairment. Further assessment of laser hazards and development of protective devices are urgently required if low-level laser emitters are to be employed in training. An assessment of high-powered microwave sources to which personnel are exposed during training and field operations is also required. Recent medical concerns have focused on the genetic, cancer-producing, and ocular effects of microwaves.

CONSTRAINTS

A general constraint to the pace of progress in health-related studies is the increasing nationwide concern over protection of human subjects in medical research. That concern has resulted in the establishment of more stringent review procedures. As a result, some categories of direct experimentation may be precluded. It is important that suitable alternatives to human test subjects be developed for experimental evaluations. Although animals still offer many possibilities, improved techniques for extrapolating results derived from animal experiments to the human must be found. Also, there is a similar growth in public concern over the use of animals in biomedical research; that also may adversely affect the pace of progress in health-related research.

2 Space*

HIGHLIGHTS

- The Space Shuttle made its first flight in April 1981. It will be able to carry larger and more diverse payloads into space at lower cost than current expendable launch vehicles can, and future flights are completely booked for several years. Upgrading of shuttles in production and development of systems for use with the Shuttle to increase its capabilities will be required to meet the needs of projected civil and military payloads.
- Sensing of Earth and its environment from space can contribute significantly to the acquisition of knowledge for furthering that understanding and devising methods to alleviate the adverse effects of mankind's actions.
- The growth of satellite-based communications has been rapid and is expected to continue. Foreign government and industry teams are becoming increasingly active in the satellite communications market. Saturation of the currently used portion of the electromagnetic spectrum and of the geosynchronous arc is impending. Application of new technology and use of yet unused frequency bands can improve the use of those resources, but data storage, processing, and management capabilities may become as limiting as communications capabilities.
- The Shuttle's availability and the Nation's background of successful space missions provide a strong foundation for the next generation of space science investigations to determine the origin and evolution of the universe and to learn the lessons that the history of the universe has for preserving Earth and its ability to support intelligent life. Other nations are undertaking work in selected areas of space science.
- The number of countries with space capabilities is increasing. That increase is creating competition for the United States, but it is also providing opportunities for cost-sharing cooperation in areas not limited by national security or commercial proprietary considerations.

INTRODUCTION

The use of space to solve problems on Earth, to expand knowledge about life and the universe, and to serve national defense needs involves missions that take years from conception to launch and that, once launched, may operate in space for several years. Space plans must look many years into the future; studies, research, and technology development must be conducted for several years before systems to satisfy mission requirements can be initiated. This approach makes possible the continuing of missions in the various areas of the Nation's space program to form a logical, efficient, and effective sequence of activities that will take advantage of technological opportunities and solve problems the Nation can be expected to face. For those reasons, the material in this section covers a span of activities from the study of concepts and development of enabling technology to the employment of space systems, many of which will not be completed until well after the 5-year horizon of this report.

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*Participants in the task group developing this section included representatives of the National Aeronautics and Space Administration, the Department of State, the Department of the Interior, and the National Oceanic and Atmospheric Administration in the Department of Commerce.

The United States has been in the forefront in exploiting the advantages that space offers. Both the National Aeronautics and Space Act of 1958 and the President's Space Policy of 1978 commit this country to leadership in space. Operation of the Space Shuttle starting in 1982 will significantly improve U.S. abilities in most areas of space activity, laying the foundation for long-duration human occupancy of space, and further space exploration.

The Nation's space program is contributing to the future quality of life on Earth. However, as with most activities that provide major benefits, space activities require a substantial investment of resources. In addition, since it is often impossible to predict accurately the benefits that a specific space program will provide, private enterprise in the past has generally not ventured into major space programs, making government sponsorship necessary.

The U.S. space program of the 1960s concentrated on developing technology for propulsion, power, structures, controls, and electronics for space systems, on initiating exploration of the solar system, and on proving that space flight, both unmanned and manned, is not only technologically feasible, but potentially very useful. The decade of the 1970s was a period of consolidation and application of the technology developed in the 1960s, initial development of reusable space systems, and assessment of directions to pursue in further space research and applications. Those directions favored utility, but the exploitation of the space environment for scientific purposes also received support. The Nation committed itself to the Space Shuttle, but it also developed and flew planetary and Earth-orbiting missions to increase understanding of the universe. Space activities in the 1980s are expected to become progressively more international in character, sophisticated in technology, rich in contribution to scientific knowledge, and valuable in utility, commercial participation and promise, and military application.

A major objective in the early 1980s will be to develop and demonstrate technology that will make space systems and missions more affordable with greater industry involvement in the early stages of technology development. Increased capabilities at lower unit costs will be sought for transportation, information, electrical energy, and operations services. Emphasis will be placed on such emerging technologies as automation embodied in autonomous spacecraft, remote manipulation systems, smart sensing, automatically sequenced operations, and efficient information systems that will screen and process data before transmitting them to Earth. Further, reduction in life-cycle costs will be sought through technology advances in aerothermodynamics, materials and structures, and electrical power and propulsion.

SPACE TRANSPORTATION AND OPERATIONS

Demonstration, in the 1960s and 1970s, of the technological feasibility and utility of space operations brought with it recognition of the need to be able to do more things in space, at less cost. That recognition led to initiation of the Space Transportation System, a combined reusable launch and reentry vehicle and a short-term, low-Earth-orbit space platform. Although at that time many of the payloads for the system and the total amount of traffic could not be predicted, the system is now solidly booked for its early years of operation. Some planned payloads will require greater services, more power, and longer stay times in space than the current system will be able to provide. Organizations committed to use of the system include the National Aeronautics and Space Administration (NASA), the Department of Defense, other agencies of the U.S. Government, commercial concerns, and foreign governments.

SPACE TRANSPORTATION SYSTEM

Progressively through the 1980s, the Space Transportation System is expected to replace for the United States the expendable launch vehicles on which all space programs have relied. It will consist of the Space Shuttle, the European-developed Spacelab, and upper stages for boosting payloads from the Shuttle's low Earth orbit to higher energy orbits. The Shuttle will be able to transport into space a wide variety of payloads as large as 15 feet in diameter and 60 feet long, and as much as 65,000 pounds in weight. A Shuttle orbiter, with a Spacelab mounted in its cargo bay, will serve as a low-Earth-orbit space platform with a stay time in space of up to 7 days.

The Shuttle will also launch, service, and retrieve free-flying spacecraft, which will perform both scientific missions to increase mankind's understanding of the universe and applications missions contributing directly to applying space technology to uses on Earth. For example, beginning with early Shuttle-Spacelab missions, investigations in materials processing are planned to lay the groundwork for the commercial production of new and superior materials in space. Also, the greater access to space provided by the Shuttle is expected to increase capabilities for remote sensing from space, thereby improving management of Earth's ecology and use of its resources.

The first orbital test flight of the Shuttle was in April 1981. Regular operational flights are scheduled to begin in late 1982. They will mark the beginning, but not the maturity, of a new national capability. Improvements will be necessary to achieve the greater capabilities that advanced payloads will demand. Many new requirements will become evident only as flight experience discloses them, but one that is already known is an ability to transport heavier cargo loads into space. Satisfaction of that need will be approached through the best combination of reductions in Shuttle weight, increases in the thrust of its propulsion system, and provision of auxiliary propulsion.

Improvement of the Shuttle's performance, habitability, reliability, operational simplicity, and payload accommodations will require some augmentation of its basic subsystems. A major need is an increase in available electrical energy, both to support expected payloads and to increase the Shuttle-Spacelab's stay time in orbit. Current technology is sufficient for developing systems that could satisfy relatively short-term needs during the next 5 years. However, longer range needs indicate a requirement for increases in the efficiency and decreases in the cost of solar arrays, increases in the capacity of energy storage devices, and improvements in power-management systems. Other important needs are for techniques and equipment for servicing satellites, both near to and remote from the Shuttle.

SPACE PLATFORMS

Some future space payloads will be able to benefit from, or will require, stay times in space greater than those that even the augmented Shuttle-Spacelab will be able to provide. It is expected that the most efficient method to accommodate many of those payloads will be to mount them on platforms providing common stabilization, electrical power, cooling, and other services. Early space platforms are expected to occupy low Earth orbits, be unmanned, and be tended periodically by the Shuttle for such purposes as resupply and placement, repair, and retrieval of experiments. The need for payload accommodations is expected to grow with time, making larger multifunction platforms desirable. Structures to a certain size will be carried to space in the Shuttle's cargo bay. Larger structures will have to be transported folded up or in sections to be assembled in space, and some could be large enough to require fabrication in space. Work is in process on the assembly and fabricating techniques that will be needed and on the technology for systems to maintain the orientation and geometry of the structures.

Geosynchronous orbits are important for some purposes. For example, communications satellites benefit greatly from being in geosynchronous orbits, and some remote sensing and space science tasks require that sensors occupy geosynchronous orbits. A problem is that demand for geosynchronous systems to perform a variety of tasks is growing rapidly, while the number of geosynchronous orbit positions is not. Consideration is being given to collecting on platforms the payloads of what would otherwise be clusters of geosynchronous satellites. Geosynchronous platforms, as early low-Earth-orbit platforms, will be unmanned. Low-Earth-orbit platforms will require periodic human servicing, but geosynchronous platforms likely will be serviced remotely from great distances.

Movement of space platforms from Shuttle altitude to geosynchronous orbit will require transfer vehicles having greater lifting capabilities than those of the Inertial Upper Stage and the Spinning Solid Upper Stages being developed by the U.S. Air Force and industry, respectively, in coordination with NASA. NASA has started developing early basic technology and concepts for orbit transfer vehicles to satisfy that need, as well as to place satellites in Earth-departure and other high-energy orbits and to retrieve satellites both near to and remote from the Shuttle.

OPERATION OF SPACE VEHICLES

From its beginning the space program has relied heavily on remotely controlled systems to direct spacecraft operations. Although the use of remote control is expected to continue, many future space activities will require, or at least be able to benefit from, such increasingly sophisticated technologies as automation, machine intelligence, and robotics. NASA sponsored, in the summer of 1980, two workshops in those areas and plans to develop appropriate technology to enable the introduction of new capabilities embodying those disciplines.

The operation of manned systems introduces questions about human physiology in space and requires subsystems to provide life support for human operators. Neither the short-term nor the long-term effects of spaceflight on physiological functions are adequately understood, and methods for mitigating adverse effects are needed. Optimal patterns of work, exercise, nutrition, and sleep must be designed. Procedures for maintaining health and treating illnesses in space require new developments. Cooperation with the U.S.S.R. in the study of life sciences areas has provided this country with some scientific information and opportunities to fly experiments during the recent hiatus in U.S. manned flights. However, the long-duration stays of U.S.S.R. cosmonauts in space during recent years may have given the U.S.S.R. knowledge that this country has not shared fully. In any event, both countries still have much to learn.

ORIGIN AND EVOLUTION OF THE UNIVERSE

One area of activity in which the United States holds recognized and uncontested world leadership is space science. Past space exploration has paid significant dividends by advancing technology in electronics in general, computer technology in particular, and many other scientific and technical areas. It has added substantially to knowledge about the universe and how Earth and its inhabitants fit into that universe. The advent of the Space Shuttle places this Nation in a position to do even greater space science research.

Space science projects tend to be major undertakings with durations measured in years rather than months. Partly because of those characteristics, the projects are particulary attractive for cooperation with other nations. The United States is conducting several space science projects with Western European nations, which are displaying increasing interest in such scientific inquiry. The U.S.S.R. also has a space science program and has even indicated plans for conducting manned exploration of the planets at some time in the future.

Investigation of the origin and evolution of the universe can be addressed conveniently under four space science areas: astrophysics, solar-terrestrial physics, planetary research, and the life sciences. It encompasses Earth, the solar system, our galaxy, and the entire universe. It includes the emergence of life on Earth and possibly elsewhere in the universe. It requires study of an incredibly diverse group of objects including diffuse clouds of gas and dust, and stars and their systems of planets, comets, asteroids, pulsars, and quasars. And, until onsite measurements can be made, it must take into consideration radiation in all the frequency regions from radio waves to cosmic rays.

ASTROPHYSICS

The goal of the Nation's program in astrophysics is an understanding of the basic laws governing the universe. Achieving that goal will be no simple undertaking. Matter exists in the universe at densities ranging from the almost perfect vacuum of intergalactic space to black holes, whose gravitational fields trap even light. Temperatures range from almost absolute zero in cold degenerate matter in dead stars to multimillions of degrees in the hearts of active galaxies. The radiation emitted by astrophysical bodies is—depending on conditions within those bodies—correspondingly high- or low-energy, intense or faint, polarized or unpolarized, and highly variable or constant. Most of the radiation cannot be observed adequately from Earth because of the turbulence and opacity of Earth's atmosphere. Consequently, progress in understanding the universe must rely on observations from the vantage point of space.

Eventually the astrophysics program will provide observations of the universe in almost all the regions of the electromagnetic spectrum. Detailed studies have been made in the X-ray and ultraviolet regions, and results have brought about a complete revision of previous theories. In contrast, the extreme ultraviolet region still awaits an initial survey. Major space systems under development to provide the needed observations include the Space Telescope, Infrared Astronomical Satellite, and Gamma Ray Observatory. A variety of experiments will also be conducted on the Shuttle-Spacelab. In addition, five satellite systems are under study: one to measure the residual microwave background radiation believed to be associated with the "big bang" origin of the universe; one to open up the extreme ultraviolet region, which is among the last remaining unexplored regions of the electromagnetic spectrum; one to provide an order-of-magnitude increase in the sensitivity and spectral and spatial resolution of X-ray measurements; one to investigate the temporal variability of galactic X-ray sources; and one to perform tests of the general theory of relativity.

The Space Telescope is under development and will be launched late in the 5-year period of this report. As the most powerful astronomical telescope ever built, it will introduce a new era of space astronomy. It will be a free-flying observatory delivered into space and serviced there by the Space Shuttle. The design of the observatory will allow its focal plane instruments to be changed and updated during flight. After a number of years, the Shuttle will retrieve the observatory and return it to Earth for refurbishment. It will be a true space analog of the traditional comprehensive, flexible, long-lived, ground-based observatory. The European Space Agency is providing solar arrays, the faint-object camera, and ground support for the Space Telescope in exchange for some observing time on it.

The Infrared Astronomy Satellite (IRAS) is a cooperative project with the Netherlands, with participation by the United Kingdom. The United States is developing the telescope for the system, while the spacecraft will be the contribution of the Netherlands. IRAS will provide the first comprehensive survey of the sky to detect discrete infrared sources in the 8- to 120-micron region of the spectrum. The survey is expected to detect 1 to 10 million sources and obtain sufficient information on them for identification of the most interesting ones for intensive study. That intensive study will be accomplished with the Shuttle Infrared Telescope Facility, which will provide infrared imaging, spectroscopy, and photometry a thousand times more sensitive than Earth-based instruments can provide.

The Gamma Ray Observatory will allow observation of objects in an extremely high-energy region of the electromagnetic spectrum. It will move gamma-ray astronomy from the initial survey performed by the third High Energy Astronomy Observatory (HEAO-3) to the detailed study stage. Its measurements are expected (1) to reveal the explosive, high-energy, nuclear and elementary particle processes that occur in the universe, and (2) to provide direct evidence of nuclear reactions that are believed to lead to synthesis of elements, information on both interstellar gas and the cosmic rays that interact with the gas, and understanding of such objects as pulsars.

Future progress in astrophysics will require components for systems that evolving knowledge indicates are needed. Components for which a need is already foreseen and for which work either is or will be in process during the period of this report include high-sensitivity detectors for all wavelengths, optics for large flux collectors, and space platforms.

SOLAR-TERRESTRIAL PHYSICS

The importance of solar-terrestrial physics research lies in mankind's complete dependence on the Sun and on the Sun's constancy and predictability for maintenance of Earth's benign and delicate environment. It is now recognized that variations in the Earth-space environment create serious operational problems in ground-based and spaceborne systems that are directly related to civilian needs and national security. Solar-terrestrial environment variations affect communications, power distribution, transportation safety, and geophysical exploration. In addition, evidence is accumulating that there is a correlation between solar events and significant weather and climate changes. Mankind therefore must understand the processes that generate energy in the Sun and transform and transport that energy to Earth, as well as the interactions of that energy with Earth's space environment and magnetic field.

The Sun dominates Earth's environment in many ways. Its light supplies energy to life on the planet, and its heating effects are the driving force for weather processes. Ultraviolet radiation from the Sun heats and ionizes Earth's upper atmosphere. The continual, but variable, outflow from the Sun of ionized gas (or plasma) known as solar wind acts on Earth's magnetic field, confining it and the charged particle population to a teardrop-shaped "magnetospheric cavity." Solar wind also contributes to the energy that is the source for aurorae, magnetic storms, and Earth's radiation belts.

Solar-terrestrial research has made significant progress in identifying the structure of the Sun, the heliosphere, and Earth's magnetosphere, ionosphere, and upper atmosphere above 100 kilometers. Areas in which further understanding is needed are:

(1) The physical processes that create and control the flow of energy and mass from the Sun into the heliosphere;
(2) The electrically neutral, highly ionized gas called space plasma, phenomena associated with its flow, and its complex interactions with planetary atmospheres and magnetospheres; and
(3) The Sun's interior and its dynamics.

Two space systems currently in operation are contributing to that understanding. The International Sun-Earth Explorers (ISEE–1, ISEE–2, and ISEE–3), a collaborative project between NASA and the European Space Agency, make simultaneous multipoint measurements that are used to determine the structure and time variability of the interface between the solar wind and the magnetosphere. ISEE–3, which occupies a stable position between Earth and the Sun that allows it to intercept the solar wind about an hour before the wind reaches Earth's atmosphere, immediately transmits its data to the National Oceanic and Atmospheric Administration to provide early warning of geomagnetic disturbances, interference with short-wave radio transmissions, and similar local manifestations of solar activity. The Solar Maximum Mission, launched in February 1980, is studying solar flares and other types of solar activity during the current peak of the 11-year sunspot cycle. It also is measuring the Sun's total heat and light output. Continuation of those measurements is crucial to an understanding of the extent to which changes in the Sun's luminosity do, in fact, cause changes in Earth's weather and climate.

Currently in the planning stage is a program that has as its objective an understanding of the most important energy exchange processes that control Earth's space environment. It will seek that understanding by measuring the flow of energy and matter from the solar wind into Earth's magnetosphere.

Also under study are two missions to investigate the dynamics of the Sun's interior and atmosphere and to probe, for the first time, the solar wind very close to the Sun. Those missions will measure, indirectly, the distribution of matter inside the Sun, thereby improving understanding of the basic mechanism of energy production in the Sun's core. They will make possible, also, fundamental new measurements of relativity and gravitational theory.

To further understanding of solar-terrestrial phenomena, instruments to be flown in a series of Spacelab flights to provide coordinated, multidisciplinary measurements of the Sun and Earth's ionosphere-magnetosphere environment are currently under study and development. One particularly important Spacelab instrument will be a large telescope that will view the Sun's surface with 10 times the detail possible from Earth's surface. In addition, several satellite systems are planned:

(1) A two-spacecraft system, now under development, to study the coupling between the ionosphere and the magnetosphere at high latitudes;
(2) An international two-spacecraft system to study the entry of ions from the solar wind into the magne-

tosphere and the energizing of those ions on the flanks of the magnetosphere and in its tail (Germany will supply the module to release tracer ions, and the United States will provide the module to detect the ions inside the magnetosphere and measure their energy);

(3) A system to study properties of the Sun's corona, the processes that generate and maintain it, and how the corona gives rise to the solar wind and accelerates it into planetary space; and

(4) A system to study, in the space environment, phenomena associated with the apparently ubiquitous turbulence of plasmas.

PLANETARY RESEARCH

The goals of the Nation's planetary research program are to understand the origin and evolution of the solar system and to provide new knowledge of Earth by comparing it with other planets. Thus, in addition to developing basic scientific information on the solar system, the program increases understanding of Earth's geologic and atmospheric processes. That understanding can aid in the discovery and use of Earth's material resources and in the discovery and control of mankind's effects on the environment. With the Apollo Moon missions, the Viking explorations of Mars, and the Voyager reconnaissance flights past Jupiter and Saturn as its most visible highlights in recent years, the planetary program has not only yielded a large amount of scientific data, but has also stimulated the minds of people around the world.

The Galileo project is in process, with its launch expected in 1985 and arrival of its orbiter spacecraft and probe at Jupiter in mid-1987. The mission will be a major augmentation in the thrust of the planetary exploration program. Studies have indicated that the next mission that should be initiated is one that would use radar to penetrate Venus's dense atmosphere and map that planet's entire surface with a resolution better than 1 kilometer and a best spot resolution of approximately 150 meters. That map would reveal details of the geological history and nature of Venus, just as Mariner 9 revealed those characteristics of Mars.

LIFE SCIENCES

Life sciences research is an important facet of the study of the origin and evolution of the universe. One goal of the research is an understanding of the highest manifestation of creation: the origin, evolution, nature, and distribution of complex life in the universe and the interaction of that life with the environment. The understanding may be crucial in determining how mankind should conduct its activities to cause the least possible detriment to the terrestrial environment. Another goal of life sciences research, an understanding of the effects of the space environment on biological systems, is expected to lead to a better understanding of life processes on Earth. Also, because manned space flight is a key element of the national space program, a third goal of life sciences research is an understanding of the effects of the space environment on humans and the development of means to mitigate those effects.

Although some life sciences research can be done in ground-based laboratories, much of it requires experiments in space, and many of those experiments require the presence of humans. In the absence of manned flights since Skylab, the United States has used ground-based research to prepare for experiments on the Shuttle-Spacelab. In addition, NASA has conducted a small number of investigations jointly with the Soviets on their Cosmos missions, and the Soviets have shared with the United States some of the results from their manned missions. Although those activities have been important, the multiple, integrated studies in space that the Shuttle-Spacelab will make possible will be the key to major advances in life sciences disciplines.

The principal objective of early Shuttle-Spacelab experiments will be to achieve an understanding of such problems encountered in previous manned flights as space motion sickness, calcium loss, fluid shifts, cardiovascular deconditioning, and muscular deconditioning. In addition, basic research will address gravitational biology.

To be as effective as possible, manned space systems should be capable of sustaining themselves with minimal connection to the terrestrial biosphere. Already completed on the ground is a "breadboard" version of a fully integrated air revitalization system designed to maintain an atmosphere of constant composition without supplies of compressed or liquefied gas. Research has been initiated to develop biologically based life support systems using plants or single-celled organisms. The goal is to develop a technology base for a life support system requiring essentially only solar energy as an input, with negligible need for resupply from Earth. The scientific understanding accruing from the development of such a system will be a pacing factor in undertaking future manned space activities and could also aid in the intelligent management of Earth's biosphere in the difficult decades ahead. An adequate scientific description of the only known large closed ecological system, the terrestrial biosphere, does not currently exist. Further, human activities are disrupting that system's cycles in ways that cannot be predicted confidently and with possible implications that are not understood.

The life-in-the-universe component of life sciences research is also expected to provide information important to mankind's understanding of the origin and possible fate of terrestrial life. Two elements of a complete program are being addressed: chemical evolution and origins of life. Plans are included for addressing the three remaining important elements: interactions of biogenic elements (for example, carbon, nitrogen, hydrogen, and oxygen) that occur before the formation of small organic molecules, evolution of life after primitive life forms first appeared, and the search for intelligent life elsewhere in the universe.

SENSING OF EARTH AND ITS ENVIRONMENT FROM SPACE

Several studies have been made in recent years of whether the world will continue to be able to sustain the current quality of human life. The most recent of those studies was conducted by the Council on Environmental Quality and the Department of State. It produced the *Global 2000 Report to the President*, which concludes that, if current trends continue, the quality of human life worldwide will be seriously diminished by the year 2000. Major factors involved include food shortages, depletion of natural resources, water shortages, and changes in Earth's atmosphere. The report states further that vigorous changes in public policy around the world are needed if problems are to be avoided or minimized before they become unmanageable.

Remote sensing from space can provide policymakers with accurate and continuously updated information on Earth's resources and environment, and such global, repetitive information can be obtained by no other known means. In addition, remote sensing is the only available tool that can satisfy the requirement of viewing Earth and its environment as a single integrated system. The terrestrial system is a complex global biogeochemical harmony; development of methods for protecting it will require an understanding of how it functions, and that understanding will require viewing it holistically rather than studying its individual components—land, oceans, atmosphere, and biosphere—in isolation.

REMOTE SENSING APPLICATIONS

Remote sensing from space has already proved to be a valuable tool and promises to be an even more useful tool in the future. For example, surveys by Earth-orbiting sensor systems can monitor changes in urban and suburban residential patterns to aid in the planning needed for relieving the significant pressures that population growth is placing on finite land resources. Surveys also can furnish land use management information related to the siting of nuclear and coal-burning power plants, coastal zone development, near-surface mineral extraction, recreational needs, wildlife and cropland preservation, and land reclamation. They can provide more accurate forecasts of global crop production, show the amount of land under cultivation, and give timely information on the related factors of water, weather, and climate. As a test, the worldwide production of wheat for 1 year was predicted, with good accuracy, from data collected before harvest. The AgRISTARS remote-sensing program is expected to provide, by the late 1980s, an improved government system for forecasting the production of all major crops. More accurate crop-forecast information permits optimal agricultural production by enabling better planting, harvesting, and storage decisions. Similarly, an ability to use remote sensing in worldwide inventorying of forests by type of timber has been demonstrated.

Remote sensing already provides improved local weather predictions, and more experience and advanced operational systems will increase precision. Remotely sensed data permit more precise estimation of amounts of precipitation and daily temperature extremes. Remote sensing also is capable of increasing the accuracy in detecting, predicting, and providing warning of hurricanes, tornadoes, flash floods, thunderstorms, blizzards, and dense fog. It makes possible the acquisition of important meteorological information in such data-sparse areas as oceans and locations in the Southern Hemisphere where conventional meteorological observations are lacking. It can provide continuous global and regional measurements of incoming and Earth-reflected solar radiation and Earth-emitted thermal radiation. Changes in the delicate balance of those quantities modulate Earth's climate. Consequently, their measurement would improve forecasts of seasonal conditions and climatic trends and, therefore, permit better management of food and energy resources.

Improvements in local weather predictions and in warnings of severe storms and natural disasters enable the agriculture, oil, gas, and shipping industries to operate more productively. Improved storm warnings are also of great value to the fishing industry, as are the more extensive measurements that remote sensing can provide, with essentially no lag in time, of ocean color, water temperature, wind speed, and wind direction, which collectively indicate the ability of an ocean area to support fish stocks.

Remote sensing is also beginning to play a significant role in locating and identifying air and water pollution and in determining their sources. By tracing the path of suspended material in rivers and estuaries, remote sensing can identify areas (impact zones) that would be affected by effluents from proposed factories, populated areas, and inadvertent spills. That information can be useful in land use planning, as well as in controlling pollution. Impact zones along the Atlantic Coast of the United States have already been mapped, and the Gulf of Mexico will soon be mapped to facilitate the planning of its coastal development.

The petroleum and other extractive industries are investing heavily in development of their ability to analyze remotely sensed data. Existing remote sensing technology provides a starting point for producing, within the next decade, a world geographic atlas to support energy and mineral exploration and development planning.

REMOTE SENSING SYSTEMS

Recent decisions have been made concerning responsibilities for developmental, demonstration, and operational remote sensing systems, and for managing their use. For example, the responsibility for managing the operation of the NASA-developed Landsat series of experimental land-sensing satellites is scheduled for transfer from NASA to NOAA staring about 1983, and NOAA is planning to initiate an Operational Land-Observing System, with NASA developing the required advanced sensors and data processing techniques.

The Nation's program in remote sensing is developing the required technology, techniques, and administrative procedures. It is a complex program involving a wide variety of systems. Mention of two of the major systems will indicate the scope of developmental activity.

The next step in the Nation's environmental program is expected to be the Upper Atmosphere Research Satellites system now being planned. That system will increase understanding of the chemical constituents and dynamics of the stratosphere and mesosphere and enhance current abilities for assessing threats to the upper atmosphere and its ozone layer.

The Advanced Operational Meteorological System, planned for initial operation in the early 1990s, will be the next-generation global weather satellite system and will serve as the operational follow-on to the current Tiros and Geostationary Orbit Environmental Satellite systems.

COMMUNICATIONS AND DATA MANAGEMENT

The decade of the 1970s saw phenomenal growth in international and domestic communications satellite networks. That growth surpassed all projections and created a need for communications satellites with greatly enhanced capabilities. It is predicted that communications traffic and other demands on the limited geostationary arc will result in saturation of the arc and the currently used portion of the electromagnetic spectrum in the early 1990s. Jockeying for priorities in the relatively limited region of geosynchronous orbit will continue. In addition, the trend toward larger spacecraft to occupy the limited number of positions in the geosynchronous arc will accelerate when the greater launching capabilities of the Shuttle and its upper stages become available.

The National Earth Satellite Service (NESS) has taken some steps to alleviate this situation. On January 29, 1981, NESS boosted the no longer useful SMS–1 geostationary satellite to an orbit 500 kilometers above the geosynchronous orbit altitude. If all operators of geosynchronous satellites could be assured of sufficient operational capability to execute such a maneuver at the conclusion of a satellite's usefulness, the present rapid rate of saturation of this very important volume of near-Earth space might be brought under control.

SATELLITE COMMUNICATIONS

To meet the demand for satellite communications projected for 1990 and beyond, NASA has plans to enhance its research and development role with the goal of developing, within the next decade, technology to support a communications capacity several times as large as the current capacity. NASA will direct one area of research toward opening up a new frequency band, as authorized by the World Administrative Radio Conference, through a system whose ground to space transmissions will be at the 30 gigaHertz (GHz) frequency and whose space to ground transmissions will be at the 20 GHz frequency. In addition, NASA is developing advanced multibeam antennas and onboard switching systems to increase the capacity of the 20–30 GHz band and of the currently used 4–6 GHz and 11–14 GHz bands. Part of that work will be aimed at constructing high-power transmitters using both solid-state and traveling-wave-tube amplifiers, and solid-state low-noise amplifiers. The result will be a capability to construct a highly flexible, wide-band communications network.

The wide-band communications network will satisfy many of the needs for additional communications capacity, but different provisions will be required for such other applications as emergency and disaster communications and land-mobile voice communications. Use of ultrahigh frequencies via satellite promises the low costs required for those kinds of low-volume communications. The design of the satellites will have to depend heavily on the application of multibeam techniques to provide as much frequency reuse as practical in an anticipated spectrum allocation of only a few tens of megaHertz.

The Tracking and Data Relay Satellite System (TDRSS) that will provide a capability for handling the increasingly higher data transmission rates of Earth-orbiting missions is scheduled to become operational in 1984. Low- and moderate-altitude Earth-orbiting systems initiated after 1980 are being designed to be compatible with TDRSS. Data loads in the 1990s are expected to exceed the capacity of TDRSS, and studies have been initiated to define concepts for an even more advanced system.

DATA PROCESSING REQUIREMENTS

The field of data processing is emerging as an important element in applying space-acquired data to everyday problems on Earth. Remote sensing satellites and various ground-based demands are already placing stress on the ability to process and use data efficiently and cheaply. As a result of past technological developments, the end-to-end cost of processing satellite data has decreased substantially—from about $100 per processed megabit to something on the order of $6 per processed megabit. If the current rate of decrease continues to 1990, the cost will be reduced to $1 per megabit. Even so, the annual cost of processing daily full-coverage data from an operational Earth-resources satellite could still be extremely high.

Efforts to manage the expected heavy data processing loads of the future will center on various research goals that reflect both the current problems and the solutions that may be possible later in the decade. In computer hardware, a significant improvement over magnetic disc technology is necessary for computer file memory, particularly in computers processing remotely sensed data. System architecture must provide easier access to data bases distributed nationwide and globally and allow data processing centers to use the capabilities of other centers located across the country. Increased standardization in computer software is needed to simplify management of data systems.

Research needs for the next decade indicate the importance of staying at least one step ahead of projected demands. As amply demonstrated in the 1970s, the growth of data processing requirements has consistently far exceeded expectations, and that growth is not expected to slow down soon. As the capabilities of Earth-observing satellites and communications systems continue to increase, effective data management techniques will become even more important.

INTERNATIONAL COOPERATION

It is clear that more and more countries, including less developed ones, are recognizing the benefits that space can provide. National budgets and industry investments in activities related to space are increasing. Ad hoc approaches to policymaking and funding of space undertakings are giving way to 5-year, 10-year, and longer term planning of space activity. Membership of the United Nations Committee on the Peaceful Uses of Outer Space has nearly doubled since the committee was established two decades ago. Development of independent national and regional capabilities in communications, Earth-observation systems, and launch vehicles is a visible result of growing international interest and investment. In addition to the United States and the U.S.S.R., the nations of Western Europe (individually and collectively), Canada, Japan, India, Brazil, and China all have active space programs.

While those growing independent capabilities make a number of nations stronger competitors for the United States in a commercial sense, they also make those nations more valuable partners for space endeavors. Thus, this country must ensure, in the years ahead, that it will be able to continue to compete effectively in such areas as satellite communications and that, in planetary exploration, for example, it has the recognized expertise that will encourage other nations to seek cooperative ventures with it.

The United States has a variety of cooperative programs with other nations, a few of which have been mentioned earlier. The largest and most ambitious program is Spacelab, developed by 10 European countries under the management of the European Space Agency (ESA) and to the joint requirements of NASA and ESA users. Spacelab will be operated by NASA. Another example is satellite-aided search and rescue. NASA is working with Canadian and French agencies to develop and demonstrate a satellite system that will locate ships and aircraft in distress by monitoring the emergency beacons they carry. The Soviets are developing a similar system and have agreed to make it interoperable with the U.S./Canadian/French system.

International cooperation helps the less developed countries profit from such space activities as communications and Earth observation. Planning is in process for the Second United Nations Conference on the Exploration and Peaceful Uses of Outer Space (UNISPACE), scheduled for 1982. The first such conference since 1968, it will focus on the practical benefits of space activities, particularly for the less developed countries.

Opportunities for international cooperation and competition will increase during the next few years, both because the number of countries with space capabilities is increasing and because the capabilities of some of those countries are maturing. Recognition of common interests and global benefits will be important to the United States in achieving the political and budgetary advantages of international cooperation while realizing the monetary rewards that can be gained by competing successfully.

3 Health*

HIGHLIGHTS

- Two powerful technologies—recombinant DNA and hybridoma (cell fusion)—will substantially accelerate the pace of medical science in the 1980s. Hybridoma technology is expected to revolutionize the study of the immune system and provide new hope for the treatment of serious human disorders. In addition to the medical production of hormones and vaccines, applications for recombinant DNA techniques exist in the agricultural, energy, and chemical industries.
- Cardiovascular disorders and cancer are the principal causes of death in the United States today, and prevention is viewed as the most effective approach to the control of both. Anticancer drugs, particle therapy, and radiosensitizers show promise in cancer treatment.
- Environmental factors are now recognized as having a significant impact on health. Research will be conducted on measuring the effects of toxic chemicals and radiation on humans, with particular emphasis on analyzing dose-response relationships.
- The costs to society of mental illness and of abuse of such substances as alcohol, tobacco, and drugs are staggering. Investigations of physiological and behavioral factors associated with the causes, treatment, and prevention of substance abuse will be continued.
- For new knowledge to have practical effects, it must be translated into clinical applications, moved into community settings, and evaluated. A broad variety of information transfer and technology assessment mechanisms are now being explored.
- Health services research to improve the effectiveness and economic efficiency of the health care delivery system may be needed. Particularly important is the evaluation of alternative delivery systems.

INTRODUCTION

The biomedical and clinical sciences have made extraordinary contributions to the quality of life and health in recent decades. Lately, however, the changing profile of the burden of illness and the stresses on a population becoming ever more urban and industrialized—and faced with a dramatic rise in its mean age—have created special challenges for health science. Regulatory agencies burdened with heavy mandates have appealed for increased information.

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*Participants in the task group developing this section included representatives of the following components of the Department of Health and Human Services: the National Institutes of Health; the Alcohol, Drug Abuse and Mental Health Administration; the Food and Drug Administration; the Centers for Disease Control; and the former National Center for Health Care Technology. Representatives of the Veterans Administration and the Nuclear Regulatory Commission also provided information on their health-related activities.

Innovative health research planning seeks to address these challenges. Most recently, the health agencies of the Department of Health and Human Services (HHS) have joined in a formal planning effort designed to introduce greater cohesiveness in major health research programs. A number of high-priority research initiatives calling for unique experiments in cooperative research planning and management have resulted from this effort.

An important aspect of the planning activity has been to seek more orderly and productive relationships among the department's components. One virtue of this broadened approach is a fusing of the boundaries between traditional laboratory- or clinic-oriented biomedical research and the fields of epidemiology, biostatistics, environmental and occupational health science, health services research, and the behavioral and social sciences.

Perhaps the most important planning issue confronting health research planners is concern for the stabilization of the basic science component of the national health research effort. Pending actions may establish a firm level for the number of competing investigator-initiated grants to be awarded. The ability of NIH and the Alcohol, Drug Abuse and Mental Health Administration (ADAMHA) to fund an established number of investigator-originated competitive research project grants will contribute substantially to ensuring that the Nation's biomedical science base will not be eroded.

Research project grants, however, represent only one element in the comprehensive approach required to provide a balanced program of support for health research. Although the science base forms the foundation from which new knowledge is generated, that knowledge must be translated into practical applications, clinical trials must be conducted, technology must be moved into community settings and evaluated, new scientists must be trained, research resources must be maintained, and centers of excellence must be preserved.

Highlighted below are some of the major opportunities and problems that will confront the health sciences over the next 5 years. Briefly considered are the promise and thrust of science (reflected in new recombinant DNA and hybridoma technologies); advances in addressing major national health problems; and efforts to solve societal and organizational issues related to translation and assessment of health care technologies.

THE NEW TECHNOLOGIES

Unusual opportunities for advancing human health have emerged in the last 5 years as a result of dramatic discoveries in microbiology and immunology. Those discoveries have generated two powerful technologies—recombinant DNA and hybridoma—which will substantially accelerate the pace of medical science in the 1980s. Their nature and potential are briefly reviewed below.

RECOMBINANT DNA TECHNOLOGY

Recombinant DNA techniques, which have been used in the laboratory to produce human insulin, growth hormone, and interferon, have now been introduced into the marketplace. Indeed, the prospects for applying the techniques to medicine, agriculture, energy, and other fields seem virtually limitless, and an aggressive infant industry has sprung up around the new technology. Potential applications include production of new vaccines, control of genetic disorders, improvement of agricultural yields, and production of new energy sources. The largest markets are likely to develop in the chemical and agricultural industries. Thus, it has been estimated that recombinant DNA techniques could be applied to as much as 24 percent of all chemical production. For the present, however, much of the work—largely sponsored by NIH—is concentrated on illuminating fundamental biological processes.

NIH has been the prime agency for monitoring recombinant DNA research; it has done this with the advice of an advisory committee of experts in science, law, education, and government. Earlier apprehensions regarding the safety of recombinant DNA research, however, have receded considerably, and, as a consequence, NIH has relaxed its guidelines. Meanwhile, such other Federal agencies as the Food and Drug Administration (FDA), the Occupational Safety and Health Administration (OSHA), and the Environmental Protection Agency (EPA) are examining their responsibilities for monitoring industrial developments involving recombinant DNA.

Concerns have also been expressed that basic research into molecular biology may be compromised by commercial exploitation, that commercial interest may influence the goals and nature of academic research, and that recombinant DNA work conducted on a large scale would pose threats to the health and welfare of workers and the community. Others view commercial involvement in such new technologies as an opportunity for a healthy readjustment in the traditional relationship between academia and industry.[1]

HYBRIDOMAS

Hybridoma technology, which emerged at about the same time as recombinant DNA technology, also promises to have a powerful effect on medical science. The technology depends on "cell fusion," which brings the contents of two cells within a common membrane. The most common type of hybridoma is the product of a fusion between a cancerous plasma cell that can continually live and multiply outside the body and a normal spleen cell that can produce antibodies. The body naturally produces antibodies against almost any foreign substance, but the antibody molecules tend to vary slightly in their specificity and other properties because they are produced by a variety of cells. The artificially created hybridomas create highly uniform or "monoclonal" antibodies, and, by selecting the appropriate antibody-forming cell to use in the fusion, large quantities of monoclonal antibodies against a wide variety of selected targets can be produced. Furthermore, once cloned to ensure homogeneity, hybridomas can be frozen for use at a future time. Thus a useful antibody can be generated in virtually unlimited amounts for indefinite periods of time. Commercially produced substances for research and diagnosis are now becoming available, and it is anticipated that clinically useful products will follow.

The availability of such antibodies is expected to revolutionize the exploration of immune processes. Molecular and cellular interactions, as well as genetic factors that affect immunity, may be identified. New ways may be found to manipulate the immune system, either to enhance its protective powers or to suppress destructive immune processes that occur in many diseases. As a consequence, progress should be possible in the treatment of many autoimmune disorders. Current empirical methods of transplantation immunology will be replaced by precise and quantitative methods, enhancing the capability for tissue grafting and organ transplants. Finally, the antibodies produced by hybridomas will be used as specific probes in fundamental investigations to examine the intricate nature of cellular structure and function, as well as the alterations that occur in disease processes.

The emergence of hybridoma and recombinant DNA technologies coupled with an increased understanding of the immune system now permits radically different approaches to the many still unsolved problems of immunization. Through a concerted departmentwide effort, HHS is seeking to exploit these opportunities to bring new and improved vaccines rapidly into use. Emphasis will be placed on development of a few of the most needed vaccines, including those against gonorrhea, bacterial meningitis, dental caries, hepatitis virus infections, infantile diarrhea, and herpes simplex infections.

Thus the new technology will be used to achieve mastery of the immune system, for application to infectious disease problems, and for treatment of other serious human disorders.

NATIONAL HEALTH PROBLEMS

The changing pattern of illness in the United States has posed new challenges to our ability to achieve effective disease prevention and control. Whereas infectious diseases were formerly the principal cause of death, today diseases of the cardiovascular system rank first, and cancer, which is second, has become the most feared disease among Americans.[2] Additionally, mental illness and substance abuse rank first in terms of total inpatient hospital days and in societal cost for accidents, violence, crime, and family disorder. In recent years, too, the impact on human health of environmental, chemical, and lifestyle hazards has become more widely recognized from a disease prevention perspective. How biomedical science is approaching these and other national health problems is briefly highlighted below.

HEART DISEASE

Cardiovascular diseases now account for roughly half of all deaths in the United States. They are also responsible for a heavy burden of illness and economic loss, ranking first as a cause of limited activity, Social Security disability, and hospitalization. The economic cost of cardiovascular disorders is estimated to be in excess of $50 billion annually, accounting for over one third of all years lost to illness.

Recent decades, however, have seen a decline in the death rate from these diseases: since 1950, cardiovascular death rates have dropped over 35 percent, and, most dramatic of all, over two thirds of this decline has occurred in the last 10 years. Primary prevention and improved medical treatment have played a role in the decline, but the relative contribution of each is unclear. It appears that attention to risk factors and lifestyle may be primarily responsible. This conclusion is based on the undoubted fact that in those countries where the rates are declining—the United States, Finland, Australia, and Canada—active approaches to risk factor and lifestyle changes have been adopted. In such other countries as Ireland, Scotland, West Germany, Denmark, and those of Eastern Europe, cardiovascular death rates are actually increasing. Thus, the declining mortality appears to be correlated with risk-factor modification in countries where such changes are being actively encouraged. (Those changes include greater involvement of individuals in their own health, alteration in diet, greater concern about smoking, attention to blood pressure control, and a recognition of the importance of exercise.)

Most scientists and public health experts agree that, for the future, prevention must be the main goal. This involves educating the public and the health professional on what each can do to change lifestyle and habits and to find ways to help promote behavior change. A need also exists to validate such concepts as the benefit of lowering cholesterol, the value of nutritional therapy for hypertension, and the value of treating systolic hypertension in the elderly. Insightful basic research is also needed to clarify the causes of arteriosclerosis and hypertension. For example, over 90 percent of hypertension cases are referred to as "essential" because the cause is unknown; until the cause is clearly determined, medical science will be unable to eliminate the high cost of drugs and the potential side effects that are now associated with blood pressure control.

Thus, future efforts, supported largely by the National Heart, Lung, and Blood Institute (NHLBI), will include more incisive research on the cause of heart disease, more validation of concepts and hypotheses where controversy exists, and more aggressive public and health-professional education. Such measures should lead to further decline in cardiovascular disease, perhaps to its ultimate prevention.

CANCER

Prevention is also viewed as the most effective approach to the control of cancer, of which 700,000 new cases are diagnosed each year. However, humanitarian considerations dictate a high priority for research aimed at improved treatment of individuals who now have or will have the disease. Both approaches are being pursued by the National Cancer Institute (NCI).

It is now widely acknowledged that such environmental factors as chemicals, radiation, and possibly viruses may all play a role, either alone or in conjunction with hereditary factors, in producing the complex sequence of events leading to cancer. Chemical toxicology and radiation research initiatives will be brought to bear on these factors in the next 5 years. Epidemiologic surveys to evaluate the risks of possible environmental hazards will be increased. Support for nutrition research will also be emphasized, with focus on foods and nutritional intake that might be related to the occurrence or development of cancer in man. Research on smoking and health will aim to reduce tobacco-related cancers.

Research in cancer biology has high priority in NCI programs, for new, basic information about the nature of cancer is the foundation for all other research, development, and control activities. New hybridoma technology in particular is being exploited to enhance understanding of cancer causation. This technology may permit scientists to detect cancer at a very early stage. Because the body's immune system is exquisitely sensitive, hybridoma technology enables scientists to label cancer cells anywhere in the body. It has already been demonstrated that monoclonal antibodies labeled with radioactive iodine can be used to test for the presence of cancer cells in mice. The high specificity of the monoclonal antibodies should permit scientists to kill cancer cells directly by means of radioactive substances or toxic chemicals attached to the antibodies. Thus, hybridoma technology holds considerable promise for cancer therapy.

Recombinant DNA techniques now allow single genes from such higher organisms as humans to be separated and inserted into bacteria, where they are reproduced as though they were bacterial genes. Because bacteria reproduce so quickly, many copies of the gene and its protein product can be created. These techniques were recently used by a team of scientists to produce human interferon. Gene splicing is also an important tool for exploring the genetics of cancer cells.

NCI is presently developing anticancer drugs that are less toxic to normal cells than conventional chemotherapy agents. Two avenues are being explored: second generation drugs and biological response modifiers. Second generation drugs are chemical cousins of conventional anticancer drugs but have fewer side effects. Aclacinomycin A is an analogue of the very active drug Adriamycin. Unlike Adriamycin, it does not cause hair loss or damage to heart muscles, and it is now being used in clinical trials in the United States. Biological response modifiers are substances, such as interferon, that may alter the body's immunological response to cancer. Because of the nature of those substances and their action on the host rather than on the tumor, they may be less toxic than conventional chemotherapy.

Development of particle therapy for the treatment of cancer is also an important project for the 1980s. This is a high energy form of radiation therapy that appears to be more selective in killing cancer cells and more sparing of normal cells. Three facilities for neutron therapy, one form of particle therapy, will be supported with NCI funds during the 1980s.

In the treatment of cancer, it has been noted that oxygen-deficient cells in areas of tumors where the blood supply is poor are resistant to X-rays. Radiosensitizers are a group of drugs that mimic the effect of oxygen and can sensitize cancer cells to radiation effects. Such drugs are now being tested. Animal studies in the United States and in England have proved that such compounds as the nitroimidazoles can make tumors more sensitive to subsequent irradiation. Misonidazole, currently under development by Hoffman-LaRoche, is one of the radiosensitizers being tested in NCI-supported clinical trials.

One of the best measures of progress in the treatment of cancer is the improved outlook for young adults and children in whom the disease is diagnosed. New technologies applied to treating acute childhood leukemia and Hodgkin's disease have resulted in a substantial decline in the national cancer death rate for persons under age 35. Development of such new approaches and drugs as those cited above should further improve treatment of cancer in the next 5 years.

ENVIRONMENTAL FACTORS

The impact on health of the chemical and physical characteristics of the human environment is now widely appreciated. It is possible to trace some human diseases directly to chemical and radiological exposure and to other environmental contaminants. Confronting those hazards is extremely difficult because of the need to determine socially acceptable levels of risk, ultimately a matter of values. Furthermore, the long-range economic and social costs involved in enforcing regulations to reduce contaminants below certain acceptable levels also need to be considered. Greater recognition of environmental factors as causes of disease has inspired two important initiatives whose impact should be felt increasingly in the next few years. They address important health problems posed by chemical toxicology and radiation.

Chemical Toxicology

Chemical contamination of the human environment has increased substantially over recent decades, a consequence of rapid industrial and technological change. The complex U.S. chemical industry, for example, now introduces approximately 500 new chemicals into commerce each year. Such tragic incidents as the poisoning of workers at Hopewell, Virginia, by Kepone and the poisoning of humans and livestock in Michigan by polybrominated biphenyls (PBBs) dramatically emphasize the potential for harm posed by chemical pollutants. More recently, the identification of a large number of chemical waste dumps has added urgency to the need for scientific information that identifies and characterizes those chemicals in the environment that are potentially toxic to humans.

The National Toxicology Program (NTP) is designed to strengthen the Federal Government's activities in testing those chemicals of public health concern. The program comprises the relevant activities of the National Institute of Environmental Health Sciences (NIEHS), Food and Drug Administration (FDA), National Institute for Occupational Safety and Health (NIOSH), Centers for Disease Control (CDC), and NCI. Also participating in the program are EPA, OSHA, and the Consumer Product Safety Commission (CPSC). NIOSH has assumed a key role in research related to control of occupational hazards, considered to be among the most important of toxicological problems.

Specific objectives of NTP are to increase the rate of chemical testing, expand the toxicology profiles of selected chemicals, develop and validate a series of tests and protocols more appropriate to regulatory needs, and disseminate newly developed toxicological information. The program brings together a unique mix of resources to support its toxicology research and testing functions. Its components provide essential scientific expertise in general toxicology, mutagenesis, and carcinogenesis; extensive laboratory facilities and animal testing skills; and broad experience in conducting carcinogen bioassays and human epidemiologic studies. The National Library of Medicine's TOXLINE and CHEMLINE computerized information systems support the program.

Radiation

Widespread use of radiation in medicine and industry, growing dependence on nuclear energy, and an increase in terrestrial radioactivity resulting from the mining of uranium have heightened public concern about the health hazards posed by radiation. The perception has also grown that the weapons testing program of the 1950s and 1960s may have had detrimental health effects. Further, the Three Mile Island accident at Harrisburg, Pennsylvania, has raised fears of potentially more catastrophic occurrences in the future.

In June 1981, an Interagency Radiation Research Committee submitted to Congress a comprehensive Federal strategy for research into the biological effects of ionizing radiation, as required by Public Law 95-622. The strategy is aimed at determining, to the extent possible, accurate dose-response relationships for all adverse human health effects resulting from exposure to any type of ionizing radiation, as well as improving the qualitative and quantitative measurements of actual radiation exposure. Possible approaches may include integration of basic studies in radiation chemistry with those in radiation biology, research into the basic mechanisms of carcinogenesis, research on ways to separate and measure human gene products to allow for rapid screening of populations for genetic defects, and possible epidemiological studies of all populations exposed to harmful ionizing radiation.

HEALTH AND BEHAVIOR

Mental illness and substance abuse are among the health problems causing the greatest concern in recent years. Compared to other disease categories, these rank first in total hospital inpatient days. By any standard, the overall costs to society of such illnesses are staggering, especially if one adds to the cost of treatment days in psychiatric institutions the costs in morbidity and mortality due to tobacco smoking, and the societal costs of accidents, poisoning, violence, and crime that are frequently associated with alcohol, drug abuse, or mental disorders.

Investigation of the factors associated with the causes, treatment, and prevention of substance abuse and mental disorders is the particular charge of the Alcohol, Drug Abuse, and Mental Health Administration (ADAMHA). The Veterans Administration (VA) has a substantive interest in research in this field, since 40 percent of hospitalized veterans have a diagnosis of alcoholism or a psychiatric disorder.

Much of the research supported by ADAMHA is basic, seeking to uncover the underlying mechanisms for the development of mental disorders and substance abuse. Investigations of the neurobiology of euphoria and dysphoria, developmental neurobiology, and the role of endorphins, for example, are being pursued vigorously. Studies of the structure-function relationships in the brain present a unique opportunity for major advances in the understanding of behavior. Thus, it has been hypothesized that certain forms of behavior, for example, substance abuse, can be viewed as attempts by the organism to correct a basic chemical imbalance. This has enormous implications for research on drug abuse, pain and analgesia, and mood disorders. Progress depends on the development of new methodology to address such questions at a neurobiological and cellular level, but activity in the field is intense, and rapid development may be expected.

In the coming years, ADAMHA will support investigations into the behavioral factors antecedent to illness (e.g., psychopathological processes, personality, behaviors, habits, environment), the behavioral factors resulting from illness (e.g., depression, "amotivational syndrome"), and the behavioral techniques designed to prevent, alter the course of, or treat illness (e.g., psychotherapy, behavior modification, biofeedback). In particular there will be:

(1) Research to better define schizophrenia, clinical investigations of the biological factors associated with it, genetic studies to disentangle inherited factors, and development of new antipsychotic drugs with fewer of the disabling side effects (this research priority is shared by the VA system, where 30 percent of the VA hospital beds are occupied by schizophrenics);
(2) Determination of risk factors in depression, including the influence of psychosocial and socioeconomic stress (in a related priority area, the VA is conducting research on the delayed effects of the stress of war and its bearing on the quality of life of Vietnam veterans, who often mask the problem with drugs, alcohol, or antisocial behavior);
(3) Studies of the physiological and behavioral aspects of fear and the nature and causes of severe anxiety;
(4) Studies of the aging process and its effect on memory and function, and the causes of senile dementias; and
(5) Investigation of the effects of changing family structure in the United States on individual well-being.

Alcoholism

Alcoholism and alcohol-related problems afflict about 7 percent of U.S. adults and 19 percent of teenagers. In economic terms, alcoholism costs about $43 billion annually, and, in societal terms, it is associated with half of the traffic deaths, half of the homicides, and one third of the suicides. Among offenders in prison, 83 percent report alcohol as a factor in their crimes. Added to that are the costs of child and spouse abuse, aggressive behaviors, disrupted family life, impaired adolescent developmental processes, fetal defects, cirrhosis, and other alcohol-related health problems. The National Institute on Alcohol Abuse and Alcoholism (NIAAA), in cooperation with NIH, will establish an intensive investigative clinical program to focus on the pathological concomitants of alcohol use. Additionally, NIAAA and NIH will fund investigations of the genetic basis for differential vulnerability to the effects of alcohol, studies of the metabolic pathways of alcohol, investigations of the vulnerability of various organs to the toxic effects of alcohol, and the development of diagnostic and treatment techniques relevant to alcohol-related problems.

A major constraint in alcohol studies has been the development of the necessary animal models. There is a need for animals that, like man, exhibit a preference for ethanol-containing solutions (normal laboratory animals avoid ethanol). A second type of model is needed to study the physical, metabolic, and psychological changes associated with long-term heavy alcohol use. Finally, there is a need for development of an animal model to study genetic factors in relation to alcohol use. Such a model is critical to correlation of alcohol-related differences with biochemical or physiological variables in elucidating the mechanism of alcohol action.

In a related program, the VA is investigating the causes and treatment of alcoholism. The program presents an ideal opportunity to attack a major health problem of veterans while performing basic research on the causes and pathogenesis of the disease. Consultation with alcoholism experts indicates that study of genetic predisposition and biochemical factors offers the greatest prospect for advancing knowledge on the subject.

Tobacco

Cigarette smoking involves one third of the national population and leads to 300,000 deaths each year. The National Institute on Drug Abuse (NIDA) has recently initiated a program that seeks to further our understanding of the causes and basic mechanisms of nicotine dependence and withdrawal and to increase effectiveness in the treatment of this public health problem. Specifically, research is planned on the biomedical, psychological, and social factors that predispose many, but not all, individuals to experiment with cigarette smoking. The program will investigate possible genetic factors influencing an individual's response to nicotine, the role of hypothesized nicotine receptors in predisposing a person to nicotine dependence, personality variables causally related to cigarette smoking, the roles that social or ethnic class and peer groups play in the initiation of smoking behavior, and behavioral and conditioning factors that influence the acquisition, maintenance, and discontinuance of tobacco smoking.

Little is known about the basic physiological and psychological effects of nicotine dependence and withdrawal. Further research is planned on the sites of action of nicotine in the central nervous system, the mechanism by which nicotine exerts its reinforcing effects, cessation of cigarette smoking, the existence of an endogenous nicotine-like substance in the brain, and the possible existence or creation of a nicotine antagonist.

Finally, there is some indication that it may be as difficult to stop smoking as to stop self-administration of opiates. Research on new techniques to help individuals reduce or eliminate tobacco smoking will be developed. Particular opportunities exist in behavior modification techniques, in educational programs to change public attitudes toward smoking, and in pharmacological therapies that replace cigarette smoking with other, less harmful behaviors.

Drug Abuse

The increasing use of marijuana and other illicit drugs in the U.S. population is one of the most striking instances of social change in the last decade. The proportion of young adults 18 to 25 years of age who have ever experimented with marijuana has dramatically increased from 4 percent in 1962 to 68 percent in 1980; the proportion who have tried illicit drugs other than marijuana in that same period increased from 3 percent to 33 percent.

Studies are planned to explore the psychological and physiological consequences of marijuana use in adolescents (effect on learning, "amotivational syndrome," effect on social development, effect on hormonal balance and sexual maturation) and to investigate the steps involved in the development of drug-using behavior. In addition, studies are needed to determine the interactive effects of alcohol with other drugs, especially marijuana; the implications of drug use in women of reproductive age; the relative carcinogenicity of marijuana and tobacco smoke; the neurological effects of inhalant abuse; and the development of new drugs for the treatment of opiate addiction.

There are theoretical reasons to believe that the neural bases of such behaviors as drug abuse, alcoholism, and cigarette smoking may involve a common mechanism. The National Institute on Drug Abuse, in cooperation with other ADAMHA institutes, will undertake investigations of such compulsive behaviors, and their underlying mechanisms, including investigations to identify commonalities between tolerance to drugs and habit formation, withdrawal, and behavioral extinction.

OTHER SCIENTIFIC OPPORTUNITIES

The years ahead present unusual opportunities for progress in biomedical science. Investigations in several fields—genetics, immunology, and molecular and cell biology—are moving forward rapidly; these areas are basic to our understanding of virtually all disease processes. The neurosciences, with their enormous potential for contributing to physical and mental well-being, are also considered promising. Yet the fundamental science bases needed to solve major national health problems are exceedingly complex; their mastery will require assiduous and continuing effort. However, promising opportunities, such as those highlighted below, will be fully exploited.

- *The Neurosciences*—Expanding technical and theoretical advances now permit progress in research on nervous system regeneration. Individual nervous system components now can be grown in test tubes, holding promise for selective implantation in humans.
- *Hormone Action*—Progress in this promising and provocative area of science, in which new significant findings are rapidly developing, is likely to contribute in the most critical way to the management of such major diseases as diabetes and other hormone-induced malignancies.
- *Diabetes*—Scientists have developed a procedure for the successful transplantation of insulin-producing pancreatic islet cells from one animal species to another. While this interspecies transplant is a unique experimental achievement, it is only a first step in possible future applications to humans. Other advances include the establishment of a causal link between a specific virus and juvenile diabetes, opening up the possibility of developing a vaccine; identification of genetic markers in diabetics, suggesting that victims may someday be discovered before the disease develops; and elucidation of the mechanism of sugar cataract formation in diabetic animals and development of "inhibitors" to delay the cataract-formation process.
- *Senile Dementias*—Recent discoveries in brain chemistry and cellular and molecular biology and applications of such new technologies as computer-assisted tomography (CAT) and positron-emission transaxial tomography (PETT) should further augment our knowledge of these disorders, particularly Alzheimer's disease. A research initiative in HHS now brings together for the first time the resources of several agencies to increase the base of fundamental knowledge about senile dementias.
- *Dental Research*—A new class of molecules responsible for binding cells in place in their tissues has been identified. These molecules, called "nectins," offer a promising area of study which may ultimately contribute to treatment of damaged tissues and to artificial implants. A major effort will be directed toward development of an effective vaccine against dental caries.

TECHNOLOGY TRANSFER AND ASSESSMENT

For new knowledge to have practical effects, it must be translated into clinical applications, moved into community settings, and evaluated. The National Library of Medicine (NLM) serves as a critical national resource for transfer of biomedical information to scientists and practitioners active in research, education, and health care delivery. To facilitate the transfer, the Lister Hill National Center for Biomedical Communications (the research and development component of NLM) performs research on the organization, dissemination, and utilization of biomedical information and designs prototype information systems. Several Federal agencies, including NIH, FDA, CDC, and ADAMHA, have responsibilities pertaining to the assessment of health care technologies.

INFORMATION TRANSFER

Over the next 5 years, the Lister Hill National Center for Biomedical Communications will explore innovative approaches to the transfer of information to the practitioner, develop additional applications of minicomputer/microprocessing to library automation, and test videodisc applications for storage and retrieval of digital and audiovisual information. All of these efforts recognize that the phenomenal increase in knowledge about health and medicine requires vigorous research into principles and processes of the information sciences that are unique to or characteristic of the field of medicine and health services.

An example of innovative transfer is the "Knowledge Base Program" at Lister Hill. Here knowledge is synthesized to form a package on a particular subject for use by a specified audience, for instance, medical practitioners. A prototype of the system, applied to the field of viral hepatitis, was established in 1977 and has been subsequently refined. That experience has demonstrated the feasibility of the concept.

The center also conducts research to improve the manner in which biomedical libraries are used as well as to create wholly new and innovative information transfer systems. Areas of research opportunity, including development of both formal and informal channels of communication and expanded use of advanced computer, electronic, and multimedia technologies, have been identified by NIH and other agencies.

TECHNOLOGY ASSESSMENT

A "technology assessment" is a form of policy analysis and research aimed at determining the various impacts of a particular technology, so as to identify possible alternatives and technical choices. The NIH Office for Medical Applications of Research (OMAR) has responsibilities for such assessments.

NIH Consensus Development Conferences, which bring together recognized experts, practitioners, and the public, focus primarily on the medical and scientific aspects (e.g., safety and efficacy) of particular high-priority medical procedures, devices, and drugs and may also take into consideration the value and proper utilization of those technologies. During the next 5 years, such assessments will review promising and/or problematical medical interventions in cancer, neurology, cardiology, allergy, dental research, and other disciplines that fall within the purview of NIH.

HEALTH SERVICES RESEARCH

Health services research is needed to improve the effectiveness and economic efficiency of our health care delivery system at all levels. A primary focus of health services research and development is to provide, through policy analysis and careful evaluation of program cost-effectiveness, systematic guidance to responsible health officials for selecting among clear-cut alternative programs. This is particularly important where there are large, innovative alternative health care delivery programs that may affect a significant proportion of the Nation's population. Thus, over the next 5 years, more emphasis will be placed on ways to raise health status through research on societal and organizational problems affecting the efficient delivery of health services. The primary responsibility for supporting and coordinating such research rests with the National Center for Health Services Research. In addition, the VA has recently developed a program to improve health care services for veterans.

Among health services issues to be addressed in the coming years are current patterns of health care expenditures (including rapidly rising hospital costs); alternatives to costly, long-term institutional care for the elderly; expanded use of paramedical personnel; and wider use of computers in health care.

The increasing ability of individuals to take an active role in ensuring and maintaining their health status and their increasing interest in doing so have been recognized in health care programs. Individuals can and do share with providers the responsibility for decisions about health care. However, it is believed that more emphasis should be placed on basic lifestyles that are health promoting. A special HHS initiative will strengthen the department's activities aimed at encouraging greater participation of individuals in their primary health care.

NOTES AND REFERENCES

1. *Science*, Vol. 208, May 16, 1980, pp. 688–692.
2. Infectious diseases rank behind these, but as a group are still a major cause of illness, incurring large socioeconomic costs and placing a major burden on the health care system.

4 Energy*

HIGHLIGHTS

- The United States does not know beyond rough estimates the full extent of its mineral values, or its oil, gas, and oil shale reserves, tar sands, or geothermal capabilities. Federal lands and waters need to be inventoried to determine the quantities of energy resources existing there.
- As oil and gas prices increase, the U.S. economy will shift from oil and gas to a broader range of energy supply options. In the process, a range of changes in our scientific and technological programs will be made, both by the Government and by the private sector, during the next 5 years.
- Market forces will provide an incentive for intensive efforts to ensure an adequate supply of liquid fuels through increased exploration, development, use of enhanced oil recovery techniques, and production of synthetic and other liquid fuels.
- Efforts will be made to increase supplies of gas through aggressive exploration, extraction of commercially viable supplies from unconventional sources, improvements in coal gasification technology, and continued negotiations to procure supplemental gas supplies from other countries at reasonable prices.
- Long-range R&D activities will focus on acquiring a technological base necessary for industry to exploit the Nation's vast coal resources.
- In nuclear energy R&D, work will continue to improve efficiency, safety, and other characteristics of the widely used light water reactor system, and develop such augmentation or follow-on sources as the breeder reactor and technologies for the disposal of radioactive waste.
- Large-scale deployment of new energy sources and their integration into existing supply systems will require more flexible distribution systems.
- Market forces will bring renewable energy technologies into use as they become economical. Research will continue on the technical and environmental aspects of biomass, geothermal, wind, solar, and other energy supply enhancement options.
- Rising energy costs and a range of Federal actions will foster more efficient use of energy in agriculture, transportation, industry, commerce, government, and residences.
- Continued attention will be devoted to basic research, as an underlying foundation for such new energy technologies as fusion.

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*Participants in the task group developing this section included representatives of the Department of Energy, the Department of the Interior, the Department of State, the Environmental Protection Agency, the Nuclear Regulatory Commission, and the National Aeronautics and Space Administration.

INTRODUCTION

The United States developed economically in an environment that included readily available and relatively inexpensive energy supplies. With the oil embargo of 1973 and the subsequent rapid increase in the cost of imported oil, there began a growing national awareness of the vulnerability of the United States to potentially unstable world oil supplies. Its position as a world power gives the United States a vital stake in the economics and energy supplies of other free world countries.

Growth in consumption of energy in the United States is moderating significantly as conservation measures brought on by higher prices begin to take effect (Figure 1). The challenge ahead is to provide a healthy economy and policy environment to make rational energy production and consumption decisions that reflect the true value of the Nation's resources. This is departing from the policy in 1973 and 1974 in which regulatory emphasis was overwhelming.

Recent Department of Energy (DOE) forecasts of U.S. economic growth have dropped substantially; as a result, overall energy consumption is projected to grow at slightly more than one percent per year from 1979 to 1990, well below the two percent per year forecast less than 2 years ago (Figure 2). Total domestic energy production in 1990 also is expected to be lower than projected earlier, at least partially because of delays in the completion of nuclear power plants.

Although overall U.S. demand for energy is projected to increase slowly, the mix of sources and uses is expected to change considerably in the next decade (Figure 3). Oil, which met 43 percent of U.S. energy needs in 1979, is expected to meet only about 35 percent in 1990. Coal use would increase from 19 percent to 27 percent of total energy use, with smaller increases in nuclear power and renewable resources.[1] Conservation would permit overall energy use in the residential and commercial sectors to remain about the same. Use of energy for transportation would decline significantly, and the industrial sector will continue the trend toward increasingly efficient energy use.

The U.S. energy policy in the past relied to a large extent on Federal intervention and attempted to protect U.S. consumers from the reality of higher world oil prices. This Administration's reformulation of Federal policies affecting energy is part of the President's Comprehensive Program for Economic Recovery, which in-

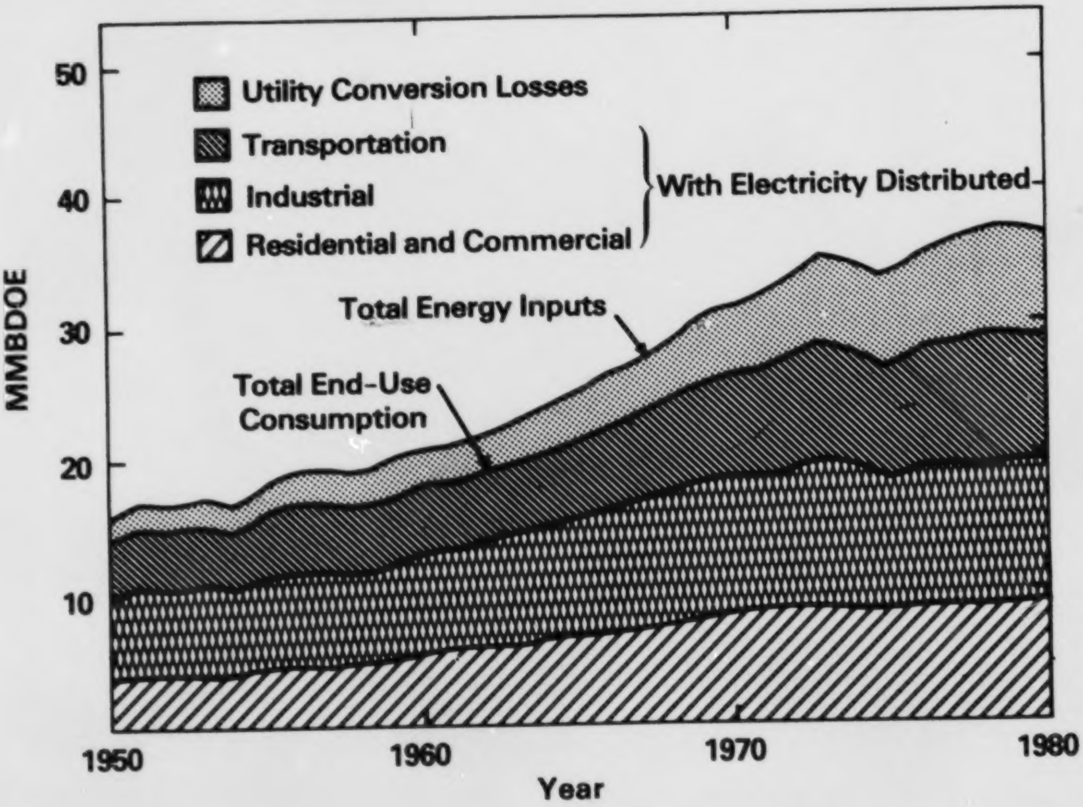

Figure 1. Consumption of Energy by End-Use Sector 1950–1980.

Source: DOE, Notice of Public Hearings and Staff Working Paper: Public Discussion Package for the Third National Energy Plan. DOE/PE-0022. March, 1981.

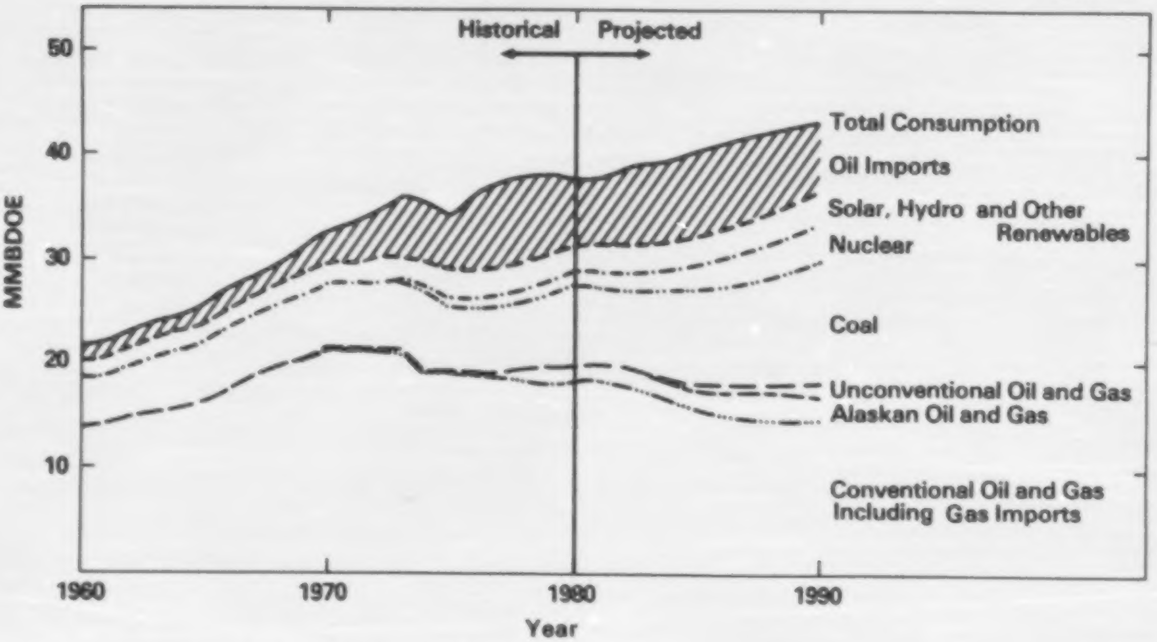

Figure 2. U.S. Energy Production and Consumption to 1990 (Best Estimate Case).

Source: DOE, Notice of Public Hearings and Staff Working Paper: Public Discussion Package for the Third National Energy Plan, DOE/PE-0022. March, 1981.

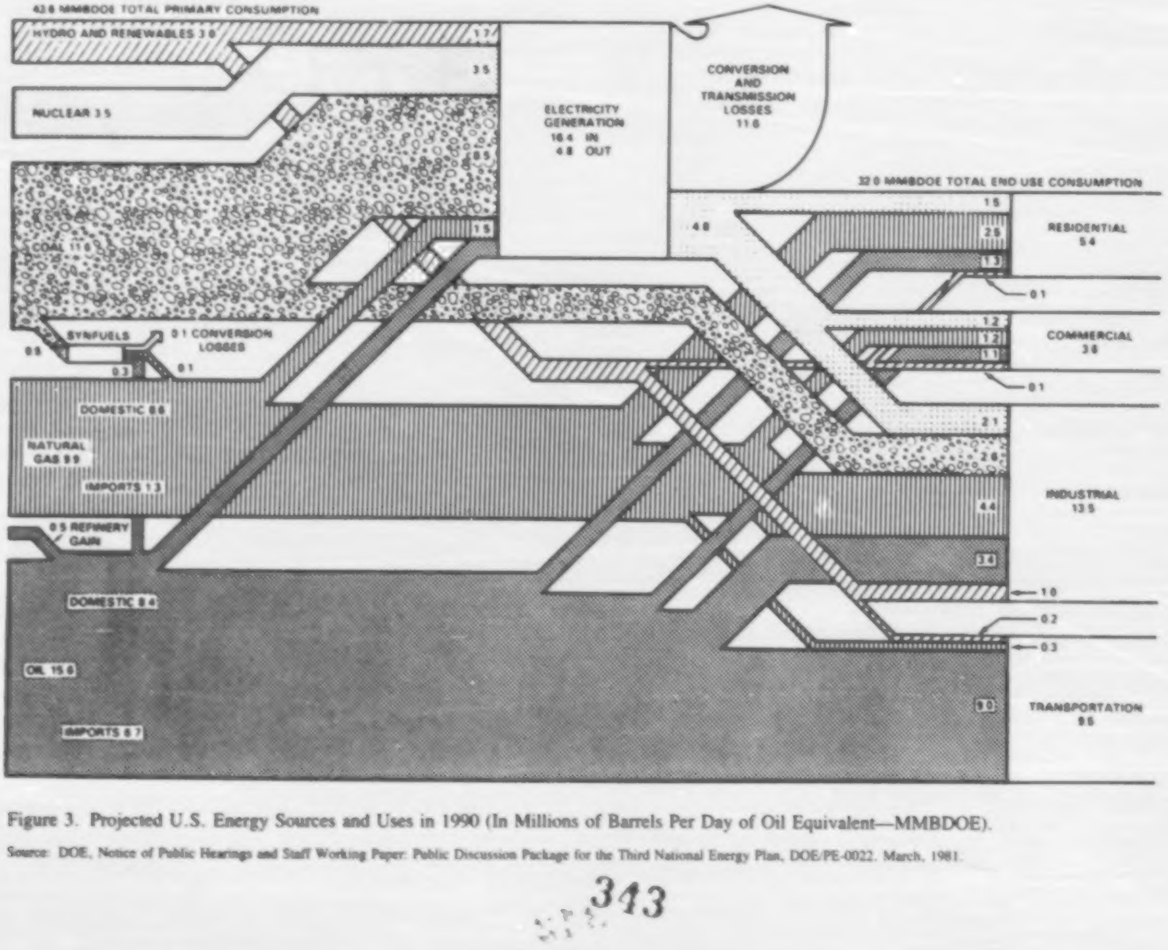
42.6 MMBDOE TOTAL PRIMARY CONSUMPTION
HYDRO AND RENEWABLES 3.0
1.7
3.5
NUCLEAR 3.5
8.5
COAL 11.6
1.5
SYNFUELS
0.5
0.3
0.1 CONVERSION LOSSES
0.1
DOMESTIC 8.6
NATURAL GAS 9.9
IMPORTS 1.3
0.5 REFINERY GAIN
DOMESTIC 8.4
OIL 15.6
IMPORTS 6.7
ELECTRICITY GENERATION
16.4 IN
4.8 OUT
CONVERSION AND TRANSMISSION LOSSES
11.6
32.0 MMBDOE TOTAL END USE CONSUMPTION
4.8
1.5
2.5
1.3
RESIDENTIAL 5.4
0.1
1.2
1.2
1.1
COMMERCIAL 3.8
0.1
2.1
2.6
4.4
3.4
INDUSTRIAL 13.5
1.0
0.2
0.3
9.0
TRANSPORTATION 9.5

Figure 3. Projected U.S. Energy Sources and Uses in 1990 (In Millions of Barrels Per Day of Oil Equivalent—MMBDOE).

Source: DOE, Notice of Public Hearings and Staff Working Paper: Public Discussion Package for the Third National Energy Plan, DOE/PE-0022. March, 1981.

cludes elimination of excessive Federal spending and taxes, regulatory relief, and a sound monetary policy. In the case of energy-related R&D, Federal spending will be considered only in those promising areas of energy production and use where the private sector is unlikely to invest. With respect to innovation, history of venture capital shows that risk taking will always be done privately when financial resources are available—in the hope of greater financial gains. Hence, collective judgment of properly motivated technical innovators, businessmen, and consumers is generally superior to any form of centralized programming.

Federal support will continue for long-term generic and technology base research with high risks but potentially high payoffs. However, public funds will not be used to accelerate private sector development of new technologies or to directly subsidize domestic energy production or conservation, since this will buy little in additional security and tends to divert capital, workers, and initiative from uses that contribute more to society and the economy.

Government and industry efforts to ensure adequate future energy supplies include:

(1) Emphasizing research and development geared toward longer term, high-risk efforts to expand all domestic energy supplies—both conventional and nonconventional—for dispersed and centralized applications; and to provide technologies for conserving energy use;
(2) Immediately decontrolling domestic oil prices to reduce oil imports as much as possible.
(3) Greatly increasing domestic (and, where possible, foreign) exploration for new oil and gas;
(4) Taking action to stimulate the use of coal, oil shale, nuclear, and renewable fuels;
(5) Increasing the size of the U.S. Strategic Petroleum Reserve;
(6) Increasing the rate at which more abundant fuels are substituted for scarce fuels, and integrating alternative renewable energy sources into the national energy system;
(7) Addressing environmental and safety impacts of fossil energy resource production, transport, conversion, and usage;
(8) Balancing various energy initiatives so that required energy is available at realistic market cost to the user; and
(9) Reducing the ratio of energy growth to Gross National Product (GNP) growth to below 0.5 through delinking economic growth from energy consumption without restricting lifestyles of U.S. citizens.

Moving from discussion of this new Federal energy policy perspective, the remainder of this section will examine the outlook for ways that S&T is likely to interact with current and emerging national energy issues.

FOSSIL ENERGY SCIENCE AND TECHNOLOGY

Fossil energy R&D efforts will include emphasis upon the problems associated with commercial production of synthetic fuels, as well as development of technologies that will lead to increased recovery and production of fossil fuels from both conventional and nonconventional sources. It has been variously estimated that economically recoverable oil reserves in the United States will be exhausted within 30 to 100 years—depending upon usage levels, new exploration success rates, and other aspects. However, the total domestic fossil energy resource base, including coal, oil shale, tar sands, and gas, is extensive, and considerable appropriate technology is available or capable of being developed to use those sources to produce useful energy.

Table 1 displays the estimated fossil energy resource potential. It illustrates a range of geologic uncertainties about the recovery of unconventional gas and enhanced oil, and it shows that the Nation's most abundant resource is coal rather than the liquid or gaseous forms of energy currently most in demand. However, industrial technologies are expected to evolve that can produce heat or steam for electrical or production processes, thus facilitating shifts to coal where economic, environmental, and other potentially constraining forces can be managed effectively. In the transport sector, in mobile equipment, and in many stationary situations where coal is not practical (due to space limitations, environmental regulations, economics of the industrial process, etc.) continued use of liquids or gas is anticipated, but those fuels will begin to be produced from coal and perhaps oil shale.

In the United States, market conditions to stimulate increased exploration and domestic production from fossil energy resources now exist, particularly since oil prices have been decontrolled and the Administration has made efforts to improve the economic investment climate through regulatory and tax reforms.

LIQUID FUELS SCIENCE AND TECHNOLOGY

For the foreseeable future, the Nation and the world must have an ensured, adequate supply of liquid fuels. To meet that need in the United States, we can expect continued efforts by the private sector to increase exploration for extractable petroleum and to develop alternative liquid fuel sources from coal, gas, and biomass.

Oil Exploration

Until economically competitive, alternative energy sources are developed to supplement declining oil and gas resources, exploration for new gas and oil resources must be intensified. While the probability of finding major new resources is a controversial topic among oil experts, some prominent, successful explorationists have stated that there is an excellent chance of finding new fields.

Table 1—Estimated Domestic Fossil Energy Total Resources and Recoverable Resources

	Billions of Barrels Oil Equivalent	
	Estimated Total Resources[1]	Estimated Recoverable Resources[2]
Conventional Oil and Gas[3]		
Oil—Reserves (incl. inferred)		57
Undiscovered		50–127
Subtotal		107–184
Gas—Reserves (incl. inferred)		59
Undiscovered		47–95
Subtotal		106–154
Coal[4]		
Reserves	1,600	900
Inferred and Thin Seams	4,500	1,300–2,300
Subtotal	6,100	2,200–3,200
Oil Shale[5]		
25 gal/ton or greater	600	250–350
15–25 gal/ton	400	150–250
Subtotal	1,000	400–600
Unconventional Oil & Gas		
Enhanced Oil Recovery[6]		
Light Oil	230	8–30
Heavy Oil	74	10–22
Subtotal	304	18–52
Unconventional Gas[7]		
Tight Gas	56–140	14–70
Devonian Shale	28–280	3–10
Coal-bed Methane	40–100	1–13
Subtotal	124–520	18–93

[1] Estimated resources in-place, only a portion of which are technically recoverable and a still smaller portion economically recoverable.

[2] Estimated recoverable resources based upon technology and economics assumed. The combination of these two factors is frequently expressed as an estimated recovery factor.

[3] Reserves and range of undiscovered recoverable resources based on USGS Circular 725.

[4] Reserves figure based on 0.6 recovery factor for resources in-place of 438 billion tons. Inferred and thin seams figure based on recovery factor 0.3–0.5 for inferred resources plus identified resources in thin beds and from 1,000 to 3,000 feet deep, undiscovered. Hypothetical resources excluded.

[5] Recovery factor of 0.4–0.6 assumed.

[6] Excludes estimated 30–45 billion barrels of domestic tar sands, of which about 10 percent is thought to be amenable to recovery through surface mining, and the portion of the remaining undiscovered oil which could be recovered through EOR.

[7] Excludes geopressured methane which, although a fossil energy resource, is not part of the DOE Fossil Energy Plan.

Source: Fossil Energy Policy & Strategy Fiscal Years 1982–1986.

Some believe that giant fields will be found in stratigraphic,* unconformity-associated,** and paleogeomorphic traps*** in all prospective basins, with about 30 percent of all future finds coming from mature, producing, and developing areas.[2] Until 1977, 93 percent of the world's oil wells were drilled in three countries (U.S.S.R., Canada, and the United States), an area representing only about 37 percent of the world's prospective oil and gas areas. Thus, more geological and geophysical exploration and a significant increase in drilling activity are needed in the 600 prospective sedimentary basins of the world.

At present, about 200 of the world's basins in harsh locations are essentially unexplored; however, such basins may not evolve into commercially viable operations, even with exploratory success. Numerous new territories, especially the Outer Continental Shelf of the Alaskan north slope, are key locations where main fields will be sought. Unresolved environmental issues have somewhat slowed the exploration and development of new regions, and the difficulty of operating in many of the harsh-climated but promising areas often retards or even precludes exploratory work. However, if the United States is to sustain an oil output in the 1980s at approximately the same level as current production (about 10 million barrels daily), up to 4 billion additional barrels must be located annually. (Only during 1 year in the last 30 have more than 3 billion barrels of reserves been found.) Industry is expected to improve the technology for offshore exploration and drilling operations to minimize the chances for spillages, blowouts, loss of well control, fires, or other occurrences that may damage the environment or endanger life. New technological means (for example, the use of robotics for underwater inspection in the area of deep sea oil exploration) will lower risks associated with underwater drilling and make recovery processes more efficient and less costly.

Enhanced Oil Recovery

An estimated 300 billion barrels of discovered oil remain in the United States.[3] However, conventional extraction techniques can deliver only a small fraction of the oil in place, typically between 20 and 30 percent.[4] New methods being investigated to extract increased quantities of oil include injection of steam, chemicals, or carbon dioxide. Under the most favorable economic circumstances and with the best foreseeable enhanced recovery technologies, it is likely that a maximum of some 50 billion barrels of oil can be recovered.

Many factors complicate oil extraction. For example, because oil reservoirs vary greatly in size, they may be depleted by a single well or may require several thousand wells. In addition, oil is found in traps that vary in depth from 100 feet to more than 17,000 feet, filling the open spaces between grains of rock and almost invariably mixed with water. A further complication is the variability of the weight of the oil which, if heavy, is especially resistant to water recovery techniques. Enhanced oil recovery techniques are particularly useful for such heavy oils, but the diversity of reservoir characteristics requires a variety of technological approaches.

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*Stratigraphic—The order and relative position of the strata of the earth's crust.

**Unconformity-associated—A lack of continuity between groups of stratified rocks in contact, indicative of a gap in the stratigraphic record.

***Paleogeomorphic traps—Of or pertaining to the configuration of the earth in some given time in past earth history. (Where oil may be found).

Enchanced oil recovery processes can be divided into four categories: thermal, miscible, chemical, and other. While most processes remain untried and involve high-risk technology, one process, the shallow California steam floods mechanism, is reasonably predictable. Overall, for the type of conditions encountered in reservoirs, technological mechanisms for most enhanced oil recovery processes other than steam flooding are not as yet well understood. Although the chemical recovery processes are technically the most complex, it is believed that they can produce the highest recovery efficiencies.

Many field tests, supported by laboratory investigations, will be required to evaluate methods to enhance oil recovery. The economics of the new techniques must be analyzed to ensure that investment risks are reasonable. In particular, the cost and availability of large quantities of such injection materials as carbon dioxide and surfactant must be determined. Processes using thermal techniques (involving oil combustion) will need to be evaluated for their effect on air quality, while processes requiring large volumes of fresh water must be assessed for their impact upon local water supplies.

Strategic Petroleum Reserves

In 1975, Congress mandated the creation of the Strategic Petroleum Reserve to provide the United States with sufficient stored petroleum to minimize the impact of an oil supply interruption. Although both surface tankage and undersea storage were considered, it was decided to use salt domes because of their superior stability, security, and economy. In converting salt domes to storage cavities, about seven barrels of fresh water must be injected and pumped out as brine for every barrel of storage capacity created.

Oil Shale

A major resource of oil in the United States that remains relatively untapped is oil shale. The western reserves of shale with 25 gallons per ton or higher quality could yield at least 200 billion barrels of oil.[5] The total western resource has been estimated to be over 2 trillion barrels, the largest untapped fossil fuel resource in the United States. There are three basic alternative technologies for commercial production: (1) above ground or surface retort where the shale is mined and processed through heating to produce oil and other byproducts; (2) in situ, where the retorting or heating occurs underground with no mining involved (the approach is to drill into a shale formation and fracture the shale to allow the required heat and fluid flow, with combustion sustained by pumping compressed air or recycled gases into the retort zone); and (3) modified in situ, where retorting occurs in a mined-out space in the shale deposit.

Generally, the private sector has been active in developing these technologies, and there are significant proprietary interests involved in the specifics of these processes. Pilot plants abound, and extensive laboratory testing is being carried out in order to refine understanding of process characteristics, costs, and alternatives that may improve process efficiency. Currently, the focus of the Government program is being shifted to the Synthetic Fuels Corporation, and DOE is phasing out its program of major research, development, and demonstration to concentrate on longer range research and development on topics that industry may not have incentives to address adequately, such as environmental effects. Major technical needs that might be addressed in the next 5 years include:

- Technology for preparation of the rubble bed.
- Retort operating procedures.
- Retort abandonment plans.
- Water management techniques.
- Designs for large and small shaft sinking systems.
- Development of control instrumentation and methods for in-situ retorting.

Coal Liquefaction—Synthetic Fuels

In addition to their direct combustion uses, vast national coal resources can be used to produce a family of liquid fuels that may serve to moderate the supply shortfalls and price increases expected for natural petroleum. The degree of moderation depends largely on the success achieved in coal liquefaction research and development programs (for example, Exxon Donor Solvent and H-Coal pilot plant test programs), on other industry initiatives, and on the Synthetic Fuels Corporation.

Direct coal liquefaction involves reactions of hydrogen and coal, and yields heavy, middle, and light distillate liquids—primarily fuel oil with about 20–40 percent in the lighter quality fuel category. Indirect liquefaction first gasifies coal, and then produces liquids (gasoline or light coal liquids) from the gas. Four liquefaction processes are being pursued, three direct—catalytic liquefaction, pyrolysis, solvent-extraction—and one indirect liquefaction process, and most are expected to become commercially competitive.[6] Three of the processes (two solvent-extraction methods and one catalytic liquefaction process) will likely undergo further intensive research, as they appear most likely to give positive results by 1985–1990.

GAS ENERGY SCIENCE AND TECHNOLOGY

There are a number of ways to expand the U.S. gas supply base. They include pursuing domestic synthetic gas R&D projects; procurement of gas from Alaska, Canada, and Mexico; increasing imports of liquefied natural gas (LNG); instituting phased pricing policies to encourage new gas exploration and production; encouraging shifts by industrial and residential sectors from gas to more abundant fuels; and strengthening conservation practices.

The major Federal R&D emphasis for gas is to support: (1) long-range, high-risk technology directed at development of unconventional natural gas resources, including eastern gas shales, coal bed methane, and western tight gas sands (goal is an incremental gas supply of 2-4 trillion cubic feet per year by 1990); (2) development of financial incentives for private sector R&D to speed the production of unconventional sources of gas; and (3) technologies for improved gasification of coal.

Natural Gas Production

The several dozen large companies that produce and distribute natural gas distributed 19.2 trillion cubic feet of natural gas in 1980, about 25 percent of the Nation's total energy supply. It is believed that current production levels will be achievable through 1985, when they will start to decline. There is a wide agreement that the proved natural gas reserves of the United States are about 195 trillion cubic feet (tcf), as of January 1, 1980. In addition, about 100 tcf of inferred reserves may be "proved" in existing fields through future development activities. There is considerable variation in the estimates of undiscovered natural gas in the United States. The U.S. Geological Survey projects a range of 475 to 739 tcf with a mean of 594 tcf. A recently completed major study by the Rand Corporation, however, projects undiscovered resources in the range of 143 to 209 tcf, with the most likely estimate of 170 tcf.

At the current consumption rate, present reserves will be exhausted in little more than 10 years if no new gas is found in the United States.[7] Federal actions are being taken to stimulate private sector exploration for additional sources in the United States, with new efforts to increase natural gas production in the lower 48 States continuing to receive high priority. In the very long range, it has been estimated that unexplored and deregulated deep wells below the 15,000-foot level could substantially expand U.S. proven reserves by as much as 100 trillion cubic feet.

Unconventional Gas Sources

Such sources as Devonian shales, tight sands, coal beds, and geopressurized zones can perhaps be used to produce up to 15 times the currently available gas resource, if aggressive R&D continues. Generally, it is believed that gas from unconventional sources can be used to supplement the conventional gas sources as they decline, with eastern shale and western sands being the main near-term candidates for exploitation. Coal-bed methane recovery may be demonstrated to be economical and feasible in the longer term, and use of geopressurized methane appears to be a very long term and highly speculative prospect deserving of aggressive investigations. A 5-year "multi-well experiment" funded by DOE will accelerate efforts in the private sector for recovery of natural gas from low-permeability sand reservoirs in the Colorado Piceance Basin. This is a high-risk, but potentially high-payoff R&D effort, which industry would not likely fund on its own. In addition to increasing our knowledge of gas resource potential, it should reveal efficient methods of hydraulically fracturing such formations and map more precisely how the lenticular gas formations are typically situated. Other technological advances expected include improved well-logging techniques and new diagnostic instrumentation for western tight gas sands.

Liquefied Natural Gas

Liquefied natural gas (LNG) presents a means of augmenting dwindling U.S. natural gas supplies. LNG could provide a feedstock to the massive gas distribution system that is already in place, perhaps at a lower cost than some synthetics. LNG is high in density; methane, the main constituent of natural gas, when liquefied occupies only 1/600 of the space it requires as a gas at room temperature and at atmospheric pressure. This facilitates economical transoceanic transport and storage; however, it also makes LNG extremely hazardous. The danger of accidental explosion is a matter of great concern in crowded ports, storage sites, and processing facilities.

Expanded LNG operations have been discouraged recently by the Federal Government, because the proposed projects have had undesirable economic features and could adversely affect foreign relations. At present, LNG is imported at a rate of about 0.8 trillion cubic feet per year. The existing potential supplies in the U.S.S.R., Nigeria, Indonesia, Australia, Malaysia, Trinidad, Columbia, and Chile suggest that the import rate could double in a decade. Most of the potential suppliers, however, would require long-term contracts before initiating LNG projects, due to the high front-end costs that could exceed $2 billion for each project. If LNG is to be used more extensively as a supplemental gas fuel, efforts must be made to minimize safety hazards. In addition, such alternative transport schemes as conversion of gas to methanol need further study.

Coal Gasification

A number of fairly well developed technologies exist for converting coal to gaseous fuels. The basic technology to achieve significant coal gasification production in future years is available, and by the mid-1980s the ongoing as well as planned research and development should demonstrate improved efficiency, reliability, overall performance, and environmental acceptability in gasification processes.

Highest priority is likely to be given to pressurized gasifiers that use either the entrained-bed or the fluidized-bed approach. The objectives of the national R&D effort are to improve environmental characteristics, pressurized operations, thermal efficiencies, and the reliability, maintainability, and availability of the coal-feeding and other subsystems. The ability to use a wide range of coal types is a further objective.

COAL ENERGY SCIENCE AND TECHNOLOGY

The Nation's coal reserves compose perhaps 30 percent of the world's total. Our legally and economically accessible coal resources are believed to be between 50 and 438 billion tons. Consumption rates have been slightly less than .7 billion tons per year. In the recent past, approximately 73 percent of the Nation's coal was consumed in electric utility boilers, 15 percent in coking for steel production, and 11 percent in boiler fuel.[8] Coal was used to produce about 45 percent of the Nation's electricity, with the balance being produced by oil, gas, nuclear, hydroelectric, or other sources. Coal is increasingly viewed as a short-term alternative fuel to reduce reliance on foreign oil and gas; however, environmental effects, technological difficulties, regulatory uncertainties, capital formation requirements, and other factors have kept coal's contribution below the expected level. In the longer term, liquid fuels from coal are viewed as being a potentially important contribution from the private sector, with assistance from the Synthetic Fuels Corporation.

Coal extraction research priorities include expanded work on (1) the fracture properties of coal; (2) the combustion processes of onsite gasification; (3) flame properties of coal dust explosions; (4) the processes that embed coal dust in lung tissues; (5) revegetation of strip-mined land; and (6) the nature and reestablishment of aquifers in strip-mined coal deposits.

Additional coal technology research is expected in the following areas:

(1) *Coal crushing*—investigating erosion in coal grinders and pulverizers and gaining an improved understanding of the mechanical and elastic properties of coal;

(2) *Coal pipelines*—Investigating the flow behavior of coal-water mixtures, turbulence, and erosion in the presence of multiple layers;

(3) *Coke formation*—treating the swelling and agglutination of coal particles and investigating the structure and reactivity of coal;

(4) *Coal combustion*—investigating the physical and chemical processes occurring in fluidized-bed combustion of boilers and furnaces, the removal of sulfur and nitrogen oxides from flue gases, turbulence, and combustion modeling.

(5) *Coal gasification and liquefaction research*—will emphasize the development of new technology that promises higher thermal efficiency, lower product cost, and higher product quality. Process concepts that minimize the requirements for oxygen, steam, and/or hydrogen will be sought since these factors all entail large thermal efficiency penalties.

ENVIRONMENTAL PROTECTION AND SAFETY ISSUES

DOE projections of U.S. base-case environmental trends (Figure 4) indicate significant improvement in some areas. At the national level, emissions of total suspended particulates (approximately 40 percent from energy sources) are projected to decline 22 percent between 1975 and 1990. Hydrocarbons and carbon monoxide, which are produced primarily by transportation, are projected to decline 28 percent and 45 percent respectively in the same period.[9] Similarly, emissions of sulfur oxides (primarily from coal-fired utilities and industrial boilers) are projected to remain level as improvements in pollution control offset increased coal use. Emissions of nitrous oxides from fossil fuel combustion are expected to increase 10 percent from 1975 to 1980.

On a worldwide scale, carbon dioxide (CO_2) concentrations are estimated to have increased by about 10 percent since continuous observations began in 1958. Among the various factors that have contributed to this trend are increased CO_2 emissions from fossil fuel use, a rise in global population, and a decrease in absorptive capacity for CO_2 from global deforestation and reduced atmosphere-to-ocean transfer. However, there are considerable uncertainties about the details of the absorptive capacities of the various sinks for CO_2, as well as the future rate of increase of manmade CO_2 emissions. Climate models project an increase in average atmospheric temperatures, with increasing CO_2 concentrations, but again, the uncertainties about specific amounts of change and the importance of other perturbing factors are high. While the uncertainty is high, the potential impact of a long-term global increase in average temperature of a few degrees could be very severe.[10] Consequently, there is a need for further research monitoring and assessment to gain a better understanding of the complexities of the global carbon cycle, with emphasis upon CO_2.

Sulfur dioxide and nitrous oxides, large amounts of which are produced by the burning of fossil fuels from both stationary and mobile sources, are oxidized in the atmosphere to sulfuric and nitric acids and then scavenged by rain, creating what is called "acid rain." Manmade emissions include those from industrial processes, municipal waste disposal activities, agricultural and forestry operations, motor vehicles, and home heating plants. In addition, natural sources contribute sulfur and nitrogen compounds to the atmosphere.

The United States, Canada, and other foreign countries are carrying out research to understand effects of acid rain on the productivity of agricultural crops, forests, rangelands, and wetlands; on the health and productivity of domestic food animals, wildlife, fish, and other aquatic organisms; and on corrosion of metals, painted surfaces, masonry, and materials in machinery and structures. An atmospheric deposition monitoring network is being established to help determine spatial and temporal

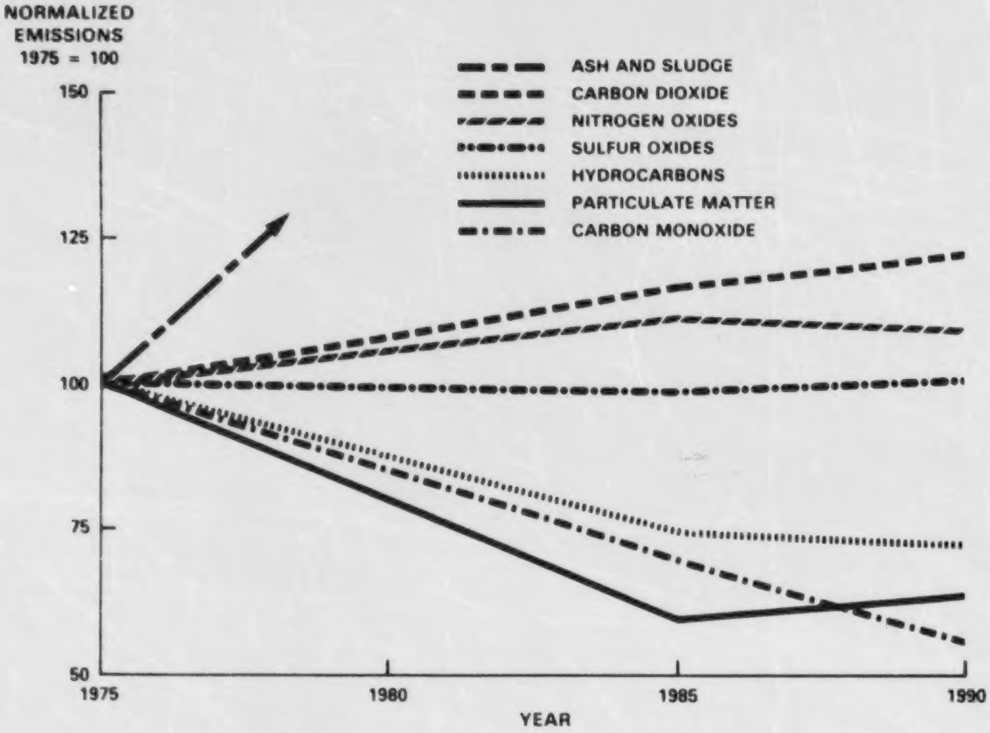

Figure 4. Projected Pollutant Emissions.

Source: DOE, Notice of Public Hearings and Staff Working Paper: Public Discussion Package for the Third National Energy Plan, DOE/PE-0022, March, 1981.

trends in the amount of injurious substances and beneficial nutrients in precipitation and dry particulate matter.

Expanded coal operations may also pose increased science- and technology-related problems in four principal areas:

(1) *Coal mining*—underground water course disruptions, "black lung" diseases, and land reclamation and surface productivity;
(2) *Coal distribution*—community disruption by new railroad facilities and increased coal industry activity, and water management problems resulting from use of slurry systems;
(3) *Combustion*—emissions of such trace elements as arsenic, cadmium, mercury, lead, fluorine, and beryllium; and
(4) *Cleanup*—coal ash and sludge disposal.

Amounts of bottom ash are expected to double as coal use increases and as suspended particulates are better controlled. Scrubber sludge resulting from sulfur oxide control is projected to increase to 31–45 million tons per year by 1990. Discharges of dissolved solids, primarily from coal mining, are projected to increase 60–80 percent in the same period. Research and development are expected to be focused on all of those problems during the next several years.

NUCLEAR ENERGY SCIENCE AND TECHNOLOGY

Nuclear energy has been demonstrated to be an economical, safe, and environmentally acceptable energy source. Starting with the United States' substantial domestic resources of uranium ore—capable of lasting well into the 21st century as used in the current generation of reactors—breeder technology can multiply the effectiveness of these resources sixtyfold, so that they could easily last for several centuries.

Two short-term barriers to greater exploitation of nuclear energy stand out: overcoming regulatory burdens and the lack of public confidence. Other concerns include the long-term adequacy of uranium supplies, the need for more efficient power reactors, and the development role of breeders and resolution of the waste disposal issue.

In recent years, between one eighth and one ninth of all U.S. electricity has come from nuclear power, and nuclear plants now generate during certain months of the year more electricity nationwide than those using hydropower, oil, or gas. Nuclear power accounts for more than half the electricity needs of some States. New plants that are now ready for operation or that are scheduled to be ready by the middle of the decade will raise total generating capacity to approximately twice what it was at the beginning of last year. Looking ahead to the early 1990s, the national share of kilowatt hours supplied by nuclear power is projected to increase to about 25 percent—based solely on plants now under construction.

In 1980, 72 nuclear plants generated more than 251 billion kilowatt hours or approximately 11 percent of the Nation's electricity. When the 104 plants that are currently in some phase of planning or construction come on line, the output from nuclear capacity will rise to about 780 billion kilowatt hours, with a capability of providing approximately 25 percent of our electricity. This contribution is significant.

For more than two decades, major breeder research and development activities have concentrated on the liquid metal fast breeder reactor (LMFBR). LMFBR technology, as contrasted to other high-technology inexhaustible resource options, is well beyond proof-of-principle stage of development and into engineering scaleup. The goal of LMFBR research is to develop the technology and engineering base to permit development of commercial breeder reactors. A sequence of developmental plants is required to permit an orderly scaleup of plant size and to provide the necessary focus for the development of breeder technology. Programs are under way to continue planned test operations of the Fast Flux Test Facility (FFTF) to construct the Clinch River Breeder Reactor Plant (CRBRP). These plant projects will be supported by a base research and development program that provides the necessary engineering and safety analysis, along with the technology improvements required for plant scaleup.

In an effort to develop technology that will significantly reduce the cost of uranium enrichment, research is being conducted on advanced isotope separation concepts. Three candidate processes—two laser isotope separation techniques and a plasma method—are being investigated. The results of this evaluation will lead to the selection in 1983 of one preferred process for engineering development toward an eventual demonstration facility and a production facility.

This Administration is committed to reversing past Federal Government excesses and to providing a more favorable climate for efficient energy production. This should allow nuclear power to compete fairly in the marketplace with other potential sources of energy supply. The President's Program for Economic Recovery can be expected to reduce inflation and improve the availability of capital to the utilities. Decontrol of oil prices encourages more cost-effective allocation and the substitution of lower cost, resource-conserving alternatives, including nuclear energy.

SHORT-TERM URANIUM AVAILABILITY

Considering existing and projected light water reactor uranium consumption rates, it has been estimated that sufficient natural uranium resources exist to meet requirements in the United States and abroad through the end of the century, and probably slightly beyond. While the amount of ore that the mining industry is confident it can produce is subject to uncertainties, approximately 1.8 to 2.4 million tons of mineable domestic uranium oxide reserves in the $30 to $50 per pound category are estimated to exist in this country.

Provisional conclusions indicate that with extensive uranium exploration and development activity, global resources could be exhausted by the year 2030. However, uranium resources can be made essentially inexhaustible through employment of advanced reactor designs—a topic that will be addressed later in this section. Also, uranium resources can be stretched out for several decades by reprocessing spent fuel from conventional power reactors or through use of thorium to generate uranium-233. Availability of thorium is estimated to be more than four times that of uranium. Lower grade uranium ore also can be used, although that could result in raising issues associated with large-scale mining, similar to those in surface-mined coal operations, and solid waste problems. Further development and subsequent use of advanced isotope separation (AIS) techniques could extend the uranium inventory.

NUCLEAR WASTE AND SPENT FUEL

Adequate disposal of high-level nuclear waste continues to be both a policy and a technological issue. Extensive efforts have been made to reduce the severity of or eliminate problems associated with waste disposal and spent fuel, and considerable success has been achieved. There is now a great deal of detailed knowledge about waste solidification, encapsulation, transport, and emplacement, and there is confidence in the ability of geologic isolation to prevent or delay radio-nuclide migration. The essential question remains exactly where (specific sites) the geologic and hydrologic conditions are such that waste isolation can be demonstrated and predicted to the satisfaction of the licensing authority, the U.S. Nuclear Regulatory Commission.

The storage and/or disposal mode for management of waste is dependent upon the characteristics of each type of waste. For example, high-level and transuranic contaminated wastes may require disposal in a geologic repository, whereas low-level wastes can be deposited in shallow land burial grounds.

The Federal program on commercial nuclear waste is aimed at providing technology for treatment, handling, and disposal of radioactive waste and for remedial actions in both government and private facilities that may become contaminated. Programs include development of criteria for identification of suitable sites for nuclear waste repositories, increased emphasis on low-level waste treatment and disposal technology, conduct of the West Valley Demo Project (Public Law 96-368), and remedial actions at uranium mill tailing sites and Manhattan Engineer District/AEC sites, as well as surplus contaminated DOE facilities.

Between now and 1985, further research will be needed on nuclear waste management, particularly on deep geological waste repositories. Research is expected to be completed on the development of more stable waste forms, on understanding the leaching of those waste forms, and on the rates and mechanisms of transport of actinides and fission products through geological media by ground waters. Those technology-base research efforts will assist in developing the understanding needed for studies and experiments on container corrosion and other radiation effects.

In addition, criteria for site selection and approval will be refined, including full consideration of the many different waste forms, their differing risk levels, leach rates, heat rates, ground-water standards, and seismic stabilities. Also, it is expected that improved methods for treatment of abandoned mines and tailings will be developed.

IMPROVING CURRENT SYSTEMS—THE LIGHT WATER REACTOR (LWR)

At present, most of the operating reactors that produce electricity commercially in the United States (and in the world) are light water reactors. They have demonstrated reliability, economy, and safety features that are comparable or superior to competitive nuclear designs. In addition, when used on a once-through fuel cycle, a LWR presents less of a proliferation threat than more advanced fission energy concepts. Unfortunately, the LWR uses uranium less efficiently than advanced reactor designs. The conversion ratio (fraction of usable fuel actually fissioned) can be improved by using different fuels, different core designs, and other means. Efficiency can also be increased by using higher temperature coolants, more efficient turbines, and other components. Those avenues will be tried in the advanced LWR program. Even very small incremental gains in reactor efficiency can result in tremendous operational and economic benefits.

While the safety record of the LWR has been commendable, additional safety research is still indicated and will focus on both operational and public safety. Most of the LWR research work will be in the basic and applied sciences; however, some effort will be expended in exploratory development. Problems of improving plant availability and fuel cycle economics will also receive attention.

Additional research topics include fuel and fission product behavior, component performance, safety technology (e.g., accident prevention and mitigation of large improbable accidents), safeguards technology, applications of computers and logic systems to power plant operations, and operator selection and training processes.

The experience gained with the LWR has given the United States insight into the nature of problems that can occur in bringing new types of reactors into full commercial use, which can take 20 to 30 years. Experimental work and systems studies have resulted in a variety of new reactor designs that would use existing fuel supplies more efficiently, while the work under way in advanced breeder systems will be refining our understanding of alternative reactors for extending fuel supplies almost indefinitely. These technologies together with better ore processing and uranium resource assessment should permit use of nuclear power for an extended period. However, in view of the long leadtimes for the introduction of a new family of reactors, there will be a continuing need to maintain an assessment of the state of the technology and of the fuel supply projections and costs, and to improve the technology readiness for alternatives to extend the fuel for the present-generation LWRs.

FISSILE FUEL BREEDER AND FUSION-FISSION HYBRID SYSTEMS

With LWRs, most of the national uranium and thorium reserves will not be used. Fissile fuel breeders, on the other hand, convert much of the natural uranium and thorium to fissile fuel, and increase the effective fissile fuel supply by about two orders of magnitude. Advanced breeders may be used by themselves or symbiotically with LWRs, to provide utilities with a predictable quantity of fissile fuel at a guaranteed price.

Objectives of the breeder development program have been to conduct broadly based R&D aimed at critical technological areas and to develop technical and engineering data that will permit selection of a breeder system for deployment after the year 2000 should policy decisions to do so be made. Critical technological areas include heat transport systems, fuel, safety, and proliferation-resistant breeder reprocessing technology. Commercialization can occur if a system with a high breeding ratio can be built at modest capital cost. The Administration is proposing initiatives to reorient the breeder program development strategy around a sequence of plant projects which determine the scalability of the technology up to sizes of commercial applicability. This effort will be supported by broadly based R&D aimed at critical technical areas including heat transport systems, safety, and fuel reprocessing technology.

ADVANCED ISOTOPE SEPARATION TECHNOLOGY

To develop a more economical technology for enrichment of uranium, DOE is supporting a program in advanced isotope separation technology. It involves the development of three processes (a plasma technique and two laser techniques) that will be operated for about 6 months in preprototype test bed facilities in 1982. Selection of one of the processes to proceed ultimately to a production facility (after development and demonstration) will be made during fiscal year 1982.

GAS CENTRIFUGE ENRICHMENT PLANT

DOE will continue to support design and construction of a Gas Centrifuge Enrichment Plant at Portsmouth, Ohio. It will have an initial production capacity of 2.2 million Separative Working Units (SWU)* beginning in 1989, with additional capacity in 1.1 million SWU increments in the 1990s. Currently operating diffusion enrichment plants meeting domestic, foreign, and U.S. Government requirements (9.9 million SWU production planned for fiscal year 1982) are located at Oak Ridge, Tennessee; Portsmouth, Ohio; and Paducah, Kentucky. Some 14 million SWU in sales next year are projected, which should result in revenues of $1.8 billion.

ENERGY CONVERSION, DISTRIBUTION, AND STORAGE SYSTEMS

The projected expanded use of coal, gas, and electricity will place stress on our existing distribution systems and, thus, has stimulated work on new ways to handle those commodities. In addition, phasing-in the variety of new technologies, developed as supplements to the use of large-scale traditional fossil, nuclear, and hydro energy sources, poses another class of integration problems. Ways that are both economically viable and technically compatible with existing networks need to be found.

In addition, advanced concepts for energy conversion systems are being explored, since advanced conversion technologies will play increasingly important roles in energy conversion and renewable resource use from 1990 onward. Technological advances in our knowledge of the fundamentals of energy release, conversion, and use could substantially increase energy productivity given the same supplies of energy, allow alternate fuel use, and help the shift to renewable sources. A greater understanding of the phenomena that affect energy conversion efficiency may lead to entirely new, significantly better methods to convert and use energy.

COAL DISTRIBUTION

Coal systems will require substantial modification and expansion if increased exploitation of western or eastern coal resources is pursued. Considerable improvements in handling equipment and distribution will be required. Slurry pipeline systems will require further research and assessment, as will possible impacts on the lifestyles of citizens affected by significantly increased rail activity. Port facilities, already overtaxed, will have to be expanded, dredged, and provided with effective new handling equipment.

GAS DISTRIBUTION

Gas in the United States is distributed through a vast national pipeline, truck, and shipping network. Future use of that distribution system will be a function of national success in augmenting, and eventually replacing, existing and depleted U.S. gas resources with synthetic gas (as well as imported LNG or natural gas). Development of gases that can be used in the existing system or a moderately modified system is a research objective. In addition, new designs are required for microprocessor control systems for burners and industrial processes, fuel-air temperature controls that respond instantly, and differential sensors to control fuel air changes. A sophisticated computer-aided gas distribution management system will enable better integration of multiple gas sources (liquefied petroleum, synthetic, and natural gas) for pipelines. New ways are also being sought to protect underground pipes, to locate them when necessary, and to excavate and backfill when installing or repairing pipelines.

ELECTRIC ENERGY SYSTEMS

Electricity distribution systems are expected to expand greatly due to increased demand from the residential, commercial, and transportation sectors. Present sources of electricity (approximately 49 percent coal, 27 percent oil and gas, 12 percent hydroelectric, and 11 percent nuclear)[11] are expected to be partially supplanted by increased use of nuclear-derived energy and energy from a variety of renewable sources. Research on technology to vary nuclear power plant output to respond to user requirements is in progress. In the meantime, use of coal-powered generators as "swing" sources will help provide required flexibility. Hydroelectric and geothermal power contributions are expected to increase in the short term; wind power systems will emerge with more abundant power in the mid term; and major solar contributions are expected in the long term.

Designs are required that will integrate inputs from an increasingly diverse set of power sources, reduce utility transmission and distribution losses, as well as increase system efficiencies through advanced control technology. In addition, environmental effects of the high voltage transmission systems will continue to be addressed through electric field effects research.

ENERGY STORAGE

When more diffuse and intermittent heat and power sources are used, the requirement for new forms of energy storage will intensify. When energy is solar- or wind-derived, mismatches between supply and demand can be significant. Consequently, research on various methods of energy storage is in progress. Mechanical storage approaches include: (1) pumping water into elevated storage basins with excess power that has been generated and reclaiming that power through a turbine generator; (2) compressing air into caverns or underground chambers and using it to power a fueled or unfueled turbine system; and (3) high energy density flywheel systems. Chemical storage research primarily examines production of hydrogen. Thermal storage technologies include simple heating of liquids and solids, heat from phase changes, and heat absorbed or released by reversible chemical reactions.

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*SWU is a measure of effort expended in an enrichment plant to separate an input stream of a given preferred isotope (e.g., U-235) into a product stream having percentage of the preferred isotope than the input, plus a "tails" stream having a lower percentage. A typical calculation for LWR system sustained by a single uranium enrichment plant would show a 9 million SWU plant representing some 22 billion Kwh equivalent energy input (enrichment being about 90 percent of total energy input that also includes mining, milling, conversion, fabrication, and reprocessing) to a reactor system that would produce a net electricity output (excluding capital energy demand) in the vicinity of 820 billion Kwh (i.e., output/input ratio of 33).

Electrical forms of storage include the high-intensity electric or magnetic fields, as well as the more conventional storage battery. Many materials combinations are being investigated in an effort to improve the energy density, cost, lifetime, and performance characteristics of current electric storage batteries. Much of this work is being done in the transportation sector, as part of electric vehicle technology development, and is discussed in the section on Electric and Hybrid Vehicles.

The Federal program in energy storage systems is long term in nature, concentrating on improving the link between energy sources and end use through R&D on design concepts and laboratory testing.

SOLAR AND OTHER RENEWABLE ENERGY TECHNOLOGIES*

Renewable and essentially inexhaustible energy sources include biomass, municipal waste, geothermal, ocean, wind, hydropower, active and passive solar heating and cooling, photovoltaics, and solar thermal. Together they now provide about 6 percent of our energy supply. These sources are generally characterized by small-scale installations with modest output power, and sources that are often diffuse and intermittent. Each of these aspects presents special scientific and technical challenges if substantial and economically viable applications are to develop. For example, small-scale installations have less flexibility to accommodate system or component failures, require special integration techniques if they feed into a common electrical grid, and are quite sensitive to subsystem costs. Similarly, intermittent sources usually require some accompanying storage device unless intermittent power can be accepted or alternate sources can be tapped. For certain of these technologies there will be a continuing need to improve the technology base, with priority given to the special problems that arise because of the characteristics outlined above. This includes work to develop better and lower cost materials resistant to the various corrosive environments, improved system performance and efficiency, improved reliability and a better understanding of how these disbursed systems interact with the larger network of energy supply systems now in place.

SOLAR HEATING AND COOLING

Direct use of solar energy is emerging as a technology with potential commercial viability for hot water and space heating of buildings, and for industrial heat processes. However, institutional, economic, and technological impediments have slowed progress. Direct solar water and space heating systems are now finding expanded application. Perhaps by the 1990s, active solar cooling may evolve to the commercial state.

Removal of subsidies for competing oil technologies, the Reagan Administration deregulation policies, the National Gas Policy Act of 1978, and various tax incentives create a more favorable climate for capital investments in solar and other renewable energy. The private sector is expected to be responsible for commercializing and developing marketable solar systems, while the Federal role will focus on basic, generic research.

SOLAR THERMAL ENERGY SYSTEMS

Solar thermal energy systems comprise both concentrating collectors and solar ponds. The potential markets for solar thermal energy systems include: (1) production of electricity by utilities serving both small and large communities; (2) production of heat or cogeneration of heat and electricity for industrial uses; and (3) production of transportable fuels and chemical feedstocks. A few complete systems have been installed in the field where potential users are obtaining firsthand experience. These include several parabolic trough systems in the 5,000 m^2 size range. Other projects under construction include the world's largest solar electric power plant (10MWe) near Barstow, California, and a parabolic dish project at Shenandoah, Georgia. Second-generation components are currently being tested in three operational outdoor test facilities. Parabolic trough systems are being sold commercially, and at least one firm is putting its own capital into developing and marketing solar thermal systems for enhanced oil recovery.

PHOTOVOLTAIC SYSTEMS

Photovoltaic (PV) energy conversion devices or solar cells, which convert light directly into electricity, are now being produced with conversion efficiencies of over 14 percent. Considerable emphasis has recently been placed on lowering PV costs to levels competitive with those of existing and projected energy sources. Development of advanced materials and large automated production facilities are expected to continue to reduce costs. Because of complex cell manufacturing technologies and relatively low efficiency, silicon and cadmium cells now sell for $5,000 to $10,000 per KW(e) of peak output, when used without concentration mirrors or lenses. Reaching costs that will permit photovoltaic systems to compete with other energy systems may require new types of devices, such as those that use thin films of amorphous rather than crystalline materials. DOE is supporting basic and fundamental research on advanced semiconductor materials for PV applications.

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* Exclusive of fusion.

HYDROPOWER

Electricity from high-head hydropower sites contributes about three percent of our national energy. Few new favorable sites remain, and attention is turning toward exploitation of low-head hydroelectric generators using a wide variety of water resources. Such small plants are virtually nonpolluting and can be esthetically pleasing. Compared to the effects of large dams, the adverse effects on small-stream ecology appear to be small. The nominal size of such installations is approximately 3 megawatts. Some 20 demonstration grants have been awarded in recent years to measure constraints of various system designs and to determine their workability. The hydropower industry has been revitalized as a result of the DOE demonstration program, streamlining of licensing procedures, credit programs, and the 21 percent investment tax credit.

GEOTHERMAL ENERGY

Commercial development of geothermal energy resources is expected to expand in the near future. Geothermal energy is becoming increasingly competitive with other energy sources as oil and gas prices are deregulated. Technology under development will increase the Nation's ability to use a larger variety of geothermal energy sources, and expanded use of existing reservoirs and lower energy production costs are expected. Geothermal potentials have been identified in over 30 States, and efforts are continuing to determine the full extent of those resources.

Federal loan guarantees have been used to encourage commercial geothermal developments, and research is being conducted to develop a better technical understanding of hot dry rock and geopressured resources, including recovery of dissolved methane; to reduce drilling costs; to develop advanced conversion systems capable of using moderate-temperature, high-salinity resources for stimulating reservoir production; and to develop better techniques for predicting reservoir performance.

An independent study by the Energy Research Advisory Board (ERAB) has concluded that "Technological emphasis should focus on the substantial impacts of improvements in drilling technology, especially in the utilization of diamond Stratapax bits, high-temperature turbo drills, well pumps, and high-temperature logging equipment".[12] It further concluded that programs dealing with geothermal well stimulation techniques should be accelerated.

BIOMASS ENERGY

Biomass is renewable organic material such as terrestrial or aquatic vegetation, and animal, agricultural, or forestry residues. The organic material can be burned directly or converted to such energy forms as liquid or gaseous fuels, or petrochemical substitutes. Applications for energy from biomass include electricity generation, production of heat and power for onsite residential, industrial, or agricultural applications, and production of liquid fuel for transportation. Areas where R&D may prove fruitful include:

(1) Aquatic biomass energy systems (microalgae, macroalgae, floating and emergent plants) that will produce marketable energy and petroleum replacement products at competitive costs;
(2) Systems for producing energy from hydrocarbon plants grown on arid lands or from high-yielding grasses grown on marginal lands, as well as systems for increasing yields of energy feedstocks that are produced jointly with food and fiber products from crops grown on traditional agricultural lands;
(3) Short rotation woody crops with yields of 8 dry tons per acre per year, for use as energy feedstocks and fiber products;
(4) Thermochemical conversion technologies for producing liquid and gaseous fuels and petrochemical substitutes from biomass feedstocks at costs competitive with fuels and chemicals derived from petroleum;
(5) Biochemical technologies for the conversion of biomass into petrochemical substitutes, and anaerobic fermentation technologies for the conversion of crop residues and other biomass into gaseous fuels; and
(6) Practical photobiological systems that will produce hydrogen from water and renewable resources.

MUNICIPAL WASTE

It is estimated that in 1980, 156 million tons of municipal solid waste and dry sewage sludge solids were potentially available for energy recovery. Should all these wastes be utilized for energy production, they could produce the equivalent of over 200 million barrels of oil annually. In addition, there is an estimated 300 trillion BTU of methane that could be extracted from existing landfill sites. Besides the potential of producing energy from waste, energy can be conserved through waste materials recycling processes and by utilization of more energy-efficient technologies by the Nation's waste-production and wastewater treatment facilities. The economics of recovering energy from urban wastes depends upon the value of non-energy materials recovered and the credit cost given relative to the cost of alternative waste disposal. Alternative systems and processes are being tested and a variety of recycling plants are being successfully operated. Problems range from emission of harmful chemicals and bad odors to inadequate capacity. Principal support for the technology is from the private sector and local governments.

WIND SYSTEMS

Wind power is a form of solar energy that has been used by man for centuries and was a significant contributor to U.S. nontransportation energy demand well into the 1900s. Wind systems are again receiving attention and a variety of designs are now available, at a range of several kilowatts to several megawatts output. The principal technical challenges in accelerating use of wind power are:

(1) improved understanding of the wind resources;
(2) development of materials and design techniques to reduce stresses that machines encounter over their lifetimes; and
(3) understanding the dynamic interactions of wind systems with the electric grid.

OCEAN THERMAL ENERGY CONVERSION (OTEC)

OTEC is a technology to exploit the temperature differences between surface and deep ocean water to generate electricity. Such a system will not require storage and, as such, will be designed for baseload option.

Among the major technical challenges associated with this technology have been heat exchanger performance and several marine subsystems, such as the large cold-water pipe, mooring, and electric cables. Extensive work has been done on heat exchanger design, since it is a critical element in the system. Currently, one major problem, bio-fouling of the heat transfer surfaces, appears to be understood well enough to enable maintenance of power system efficiency via periodic cleaning, for periods of up to 2 years. Longer periods will still need to be assessed, as well as performance of advanced heat exchanger designs intended to improve cost-effectiveness of the system. Additional questions that require assessment are the nature of climatic and ecological effects, if OTEC systems are employed in large numbers. Further work, including construction of a pilot plant, will be primarily the responsibility of the private sector.

ENERGY END-USE TECHNOLOGY AND EFFICIENCY IMPROVEMENT

Investments in increased energy usage efficiencies can be cost-effective in the near term, whereas energy from emerging technologies (geothermal, OTEC, synthetic fuels, and others) will take years to make important contributions. Although population growth and economic expansion are expected to increase demand for energy, rising energy prices are resulting in improved efficiencies. This will be important to avoid a decreased standard of living in the United States. An array of Federal Government conservation tax credits are stimulating major efforts to eliminate waste by encouraging modifications of equipment and processes, and by modifying consumer investment and energy usage habits. The Federal agencies are continuing R&D activities on generic basic research activities that the private sector is unlikely to perform. In addition, Federal grant programs are being restructured to achieve increased State and local control.

TRANSPORTATION TECHNOLOGY

The United States expends more than 30 percent of its energy resources (at least 52 percent of the Nation's liquid petroleum consumption) on transport.[13] Economic forecasts indicate that automotive energy usage will decrease during the 1980s, but will gradually increase in the following decade. Aircraft and truck energy consumption is expected to grow dramatically during the next 20 years. In the short term, improvements in the design of conventional vehicles can be achieved through down-sizing, weight reduction, streamlining, and modifications in engine design. In the longer term, new and more fuel-efficient transport technologies and alternative fuel concepts will be required.

Propulsion Systems

Many propulsion system options have been explored, primarily by the private sector, in hope of improving efficiencies while maintaining exhaust emissions below levels required by the Clean Air Act. The systems include greatly improved, small, conventional engines with advanced electronic controls, gas turbines, and Stirling engines. The alternative engine technologies that are being explored have certain characteristics that may make them attractive as standard liquid fuels increase in price and become less available. For example, the Stirling engine can be operated on a wide variety of alternative fuels, including liquid fuel of relatively poor quality.

The Department of Energy, Department of Transportation, and NASA will continue to support generic research in such advanced technology areas as combustion processes, while leaving the development of specific engine systems primarily to the private sector.

Weight Reduction

Automobile manufacturers are achieving improved fuel economy by reducing vehicle weights, which is difficult without sacrificing carrying capacity or introducing high-cost and energy-intensive materials. Materials research, possibly in synthetics and other substances, is expected to help. The reduction in vehicle weight, of course, will require special attention to crash protection design aspects.

Aerodynamic and Frictional Losses

Air resistance to the movement of a vehicle increases approximately with the square of the vehicle's speed, and the engine power required to overcome that friction normally increases with the cube of the vehicle's speed. Consequently, very small reductions in an automobile's air resistance can significantly increase efficiency. Also, future development by the private sector of lower wear and lower friction oils and lubricants to reduce other types of friction is expected.

Electric and Hybrid Vehicles

Electric vehicles, or hybrid versions that utilize mechanical storage or small conventional engines, could become a preferred mode of transportation in urban areas for commuting, for small commercial and industrial users, and for limited personal transportation. The major obstacle to extensive use is present-day batteries. Lead/acid batteries currently in use are expensive and provide very limited performance; present conventional batteries have a capacity to store 30 watt hours per Kilogram (Wh/kg). Research has concentrated on improved lead/acid, nickel/iron, and nickel/zinc batteries for the near term. For example, nickel/zinc batteries can provide a capacity of 60 Wh/kg, or a two-fold improvement over conventional lead/acid cells. Work has begun on a zinc/chloride battery and a new lithium battery, both of which are showing promise for the mid term. The major longer range possibilities include lithium/sulfur and sodium/sulfur high-temperature batteries, ambient temperature alkaline-metal technologies, and metal-air combinations such as aluminum-air.

INDUSTRIAL TECHNOLOGY

The industrial sector consumes about 38 percent of U.S. energy, and manufacturing accounts for nearly 79 percent of that total.[14] Energy savings through the exploitation of technology for cost-effective operational practices have already been significant. The increasing demand for energy-efficient products in response to rising energy costs is now stimulating industry to develop more energy-efficient product lines and to explore product-specific technologies for reducing energy consumption. In many instances, because of currently high interest rates and capital cost, retrofitting for energy conservation is still not economical. Conservation techniques are likely to be incorporated in new or replacement facilities and equipment—although replacement or expansion will require decades to make an impact.

Areas that offer industry unusual potential for improved efficiency include direct heating processes, especially in the most energy-intensive utilities and industries; recovery of industrial waste energy; and substitution of alternative energy sources for conventional fuels and feedstocks.

Government incentives, through tax credits, are available to promote fuel conversion (e.g., oil to coal), modification to existing equipment, improved process controls, etc., as defined in the Energy Tax Act of 1978. Decontrol of oil prices is also expected to have a major impact on increasing energy-use efficiency.

CONSERVATION R&D FOR BUILDINGS AND COMMUNITY SYSTEMS

The buildings sector uses about 38 percent of all primary energy in the United States, about two thirds of which is for residential buildings (about 81 million units), with the remainder used in commercial applications.[15] It has been estimated that over 80 percent of residential buildings require modifications to respond in a cost-effective way to the new energy realities, and commercial buildings can similarly profit from energy-saving technologies. R&D initiatives need to focus on gaining a better understanding of energy losses in buildings.

Private sector initiatives will be utilized to stimulate retrofitting of both commercial and residential buildings. Overall, for both industrial and residential applications, the value of tax incentives for energy conservation is expected to be approximately $800 million in fiscal year 1982.

ENERGY RESEARCH AND TECHNOLOGY BASE SUPPORT

Underlying the major programs for energy technology developments in both the public and the private sectors is a wide range of research activities that involve work in such traditional disciplines as the physical and biological sciences, geosciences, engineering, and mathematics. Those activities extend the knowledge base upon which the Nation can build future energy supply, conversion, and end-use options, and improve our understanding of the basic processes fundamental to energy systems development. The mission-oriented programs of the Department of Energy, in addition, emphasize innovative applications of new knowledge to energy problems and the early transitions of such information into commercial practice.

In general, research efforts tend to be a long-term investment with little immediate impact, since discoveries made today are destined to find their way into commercial systems many years in the future. Because of the long leadtimes and the risks involved, industry cannot provide significant support for such efforts, and government is the principal sponsor.

In the following sections, highlights of some of the more fundamental supporting research efforts in energy are described. Also included here is the nuclear fusion program because of its early stage of development.

MATERIALS SCIENCES

One purpose of work in the materials sciences is to provide the necessary base of knowledge and the new materials required to advance the Nation's energy programs.

During 1981, the Intense Pulsed Neutron Source (IPNS) located at Argonne National Laboratory, will become operational. It is designed for production of neutrons to extend our ability to study the structures of both solids and liquids.

Also in 1981, the National Synchrotron Light Source (NSLS) at the Brookhaven National Laboratory will begin to provide radiation that is stable, pulsed, high in intensity, and continuous in spectrum from the "soft" X-ray region of 10-20 angstroms through the ultraviolet range. Some of the expected applications are to study the state of behavior of gases and the surfaces of solids, to study active metal atoms in biological systems, to analyze atomic structure of microscopic samples, and to further advance knowledge about microscopy and lithography.

CHEMICAL SCIENCES

Energy-related research activities in the chemical sciences cover topics ranging from energy-related phenomena involving liquids, gases, plasmas (and the chemical properties of such solids as coal, chlorophyll, and catalysts) to phenomena and behavior of such submicroscopic particles as molecules, atoms, ions, and electrons. Some areas, like research on the chemical effects of catalysts, are expected to lead to discoveries that can be used immediately by industrial process designers to achieve previously unattained efficiencies in converting fossil fuels to more usable forms (for example, liquid fuels from coal). Other areas, like research on water-splitting photochemistry to produce hydrogen, the cleanest of all fuels, are producing results that may be attractive to solar energy technologists in the mid-term.

A major new facility in 1981 is the Combustion Research Facility (CRF) at Sandia National Laboratory, Livermore, California. It will provide a unique capability to outside users for combustion research using instrumentation not ordinarily available. The focus is on laser diagnostics of combustion systems, but several burner systems (for instance, a turbulent diffusion flame facility and a low-pressure flame facility) also are provided. In addition, special facilities for research in coal combustion and for combustion studies in an internal combustion engine are available.

BIOLOGICAL ENERGY RESEARCH

Biological energy research is aimed at developing a broad, intensive, fundamental understanding of the factors involved in plant biomass productivity and conversion of biomass and other organic materials into fuel chemicals. Current research efforts are aimed at developing deeper understanding of the mechanisms involved in green plant productivity limitations; adaptability of plants for growth and productivity under environmental stress; biological regulatory processes that determine how plants synthesize and distribute reduced carbon compounds; and biochemical expression of genetic information.

FUSION ENERGY RESEARCH

Nuclear fusion is one of the long-term options that can provide an essentially inexhaustible supply of energy (hydrogen from seawater is one fuel option), with the additional attractive characteristic that no chemical combustion products are released. Extensive R&D will be required to attain commercialization of a fusion energy production system. Two approaches are being pursued, magnetic confinement and inertial confinement; the latter, however, is further from commercialization. Fusion power costs have been estimated to be similar to fast breeder reactor power costs, although insufficient data are available to calibrate and verify the accuracy of the cost projections.

Magnetic Confinement Systems

Magnetic confinement fusion energy research is aimed at achieving controlled nuclear reactions suitable for commercial use. Scientific and technical problems of confining high-temperature plasmas (gases heated to tens of millions of degrees) at sufficient densities and for sufficient time periods must be resolved. Progress has been encouraging, especially in the last 5 years, and it now appears possible to create and control a plasma of burning fusion fuel with equipment of reasonable size. The requirements for plasma temperature, density, and confinement duration for an energy production system are close to fulfillment, although the reactor-required levels for all three have not been reached at the same time in any one machine. Near-reactor conditions will be combined in the Tokamak Fusion Test Reactor (TFTR) now being built in Princeton and scheduled for initial operation in 1982. In 1985, that machine is expected to reach energy break-even, where the energy produced equals the energy used to reach fusion conditions. Research will also continue on toroidal and mirror concepts so that the most promising fusion cores for commercial reactors can be identified and developed further. At the same time, R&D on structural materials, engineering system design, plant design, materials handling, and environmental safety will be pursued.

Inertial Confinement Fusion Systems

Research on inertial confinement fusion is aimed at demonstrating thermonuclear burns by depositing large amounts of energy (via light or heavy ion beams) in an extremely short time onto target pellets containing fusion fuel. Research and development directed toward inertial fusion energy systems serve two goals: the maintenance of a capability in the national nuclear weapons laboratories to address nuclear weapon design problems and the development of an alternative approach to fusion energy production. For the inertially confined systems for energy production, such required technologies as high repetition pellet drivers, pellet placement systems, fusion chamber materials, power supplies, and remote maintenance remain to be developed and demonstrated.

Inertial fusion is still in the exploratory development stage, with much basic research to be done toward understanding the physical processes that occur in the rapid compression and heating of very small masses of deuterium-tritium (D-T) fuel to fusion conditions. It is widely believed that only a thorough understanding of inertial fusion physics, and of very high energy and high power target driver sources at levels not now available, will make it possible to demonstrate the scientific feasibility of inertial fusion. Demonstration is not likely to occur before the end of the present decade. The highest power laser driver system under construction, NOVA, is primarily intended to study inertial fusion physics and to provide design information for advanced generating systems.

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5 General Science and Technology*

HIGHLIGHTS

- Progress in life sciences research gives every indication of continued vitality. Examples of areas receiving particular attention include genetics (both human and plant); biochemical electronics; cognitive science; and population, environment, and global resources studies.
- Extensive use of sophisticated instruments and satellite data will foster research about Earth and other planets. Specific topics for study include planetary atmospheres, evolution and dynamics of Earth, biogeochemical cycles, and ocean processes.
- Advances in physical sciences and mathematics hold promise for great national benefits. Elementary particle forces, public key cryptography, ultrarapid phenomena, and development of new materials with special properties are among a large number of topics currently of great interest.
- Engineering affects virtually every segment of society. New developments in robotics, microengineering and microstructures, information technologies, and laser technologies will contribute to the strength and welfare of the Nation.

INTRODUCTION

Activities classed as general science and technology are those that are not focused on any specific mission—applications of the research results generally are not known beforehand. That is not to say there is no urgency to their pursuit. There are many instances of unforeseen practical benefits flowing from fundamental research in science and engineering. An example is provided by the new recombinant DNA technologies, with their potential applications in agriculture and medical practice. Those technologies emerged somewhat unexpectedly from basic research on the dynamics of cellular processes. Dramatic advances of that magnitude have occurred with such frequency that their arrival now has become expected. As they surface, new devices, new processes, and even entire new fields of commercial activity can arise in a relatively short time.

Research in general science and technology stems both from the needs of mission organizations for new information and techniques to achieve their objectives and from the needs of society. Unfortunately, fundamental information about our world is frequently costly to obtain and is not ordinarily protected by patent regulations. Many commercial enterprises are therefore hesitant to sponsor such activities without financial support from the Federal Government. Other countries have undertaken collaborative efforts involving industry and government to promote the national research position; improving such collaboration in basic science and engineering also promises much for the United States.

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*Participants in the task group developing this section included representatives of the National Science Foundation, the Department of Energy, the Consumer Product Safety Commission, the Department of Agriculture, the Department of Commerce (National Bureau of Standards and National Oceanic and Atmospheric Administration), the Department of Defense, the Department of the Interior, the National Aeronautics and Space Administration, the Environmental Protection Agency, the National Institutes of Health, and the Veterans Administration.

This paper describes selected areas of research that will expand the general science and engineering knowledge base, highlighting promising areas of inquiry in the life sciences, earth and planetary sciences, physical sciences and mathematics, and engineering.

LIFE SCIENCES

Recent progress in the life sciences has been dramatic and gives every indication of continued vitality. Researchers in the life sciences are, with great success, adapting instrumentation and experimental methods developed for the physical sciences. New ways of looking at living systems, their mutual interactions, and their relationships with the environment are providing new understandings and provoking innovative lines of research and development.

GENETIC SCIENCE

Since 1953, when the Watson-Crick model of the structure of DNA was proposed, advances in understanding molecular biology have come with extraordinary speed. Two related technologies, gene cloning and rapid DNA sequencing, have opened up avenues for research and areas with promise for commercial activity. It is not yet clear when genetically engineered products will reach the market, but few doubt that they will. Possible products for commercial development include vaccines, insulin, and interferon—substances that now are very expensive and in short supply because of limited raw source materials and costly, time-consuming manufacturing processes.

The first "cloning" of mammals was accomplished recently at the University of Geneva, Switzerland. The experiment involved transplanting embryonic mouse nuclei into several recently fertilized mouse eggs from which the original nuclei had been removed. The altered eggs were then implanted in the uteri of mice and carried to birth. The prospect of extending such experimentation to humans has raised difficult ethical questions, and a debate is now building over such pursuits.

Genetic engineering of living systems (in the sense of transferring different genes into existing cells) is a more difficult but ultimately more exciting prospect. Although still at a very early stage, gene transfer research has made considerable progress. Recombinant DNA technology enables researchers to prepare individual genes that can be taken up by cells and incorporated into the inherent genetic material. Among the long-term prospects for the technology is the development of specialized organisms that can do such useful tasks as fixing nitrogen in the soil or decomposing environmentally threatening oil spills. The possibility of altering genetic materials in human cells suggests that we may be able to treat genetic diseases or predispositions for disease among human populations through gene transfer.

PLANT GENETICS

Many exciting opportunities exist in plant genetics. The selective development or alteration of plant species offers the possibility of adapting crops to increasingly stressful environmental conditions or to resource constraints. As a result of increased demands for fresh water in all sectors, the world's ground and surface waters are becoming saline or contaminated. In addition, the worldwide loss of agriculturally productive lands is forcing the cultivation of less congenial soils. Particularly in arid and semiarid regions, insufficient natural precipitation requires the extensive use of irrigation, and frequently the water used has high levels of various salts. Moreover, increased usage of ground waters in coastal regions is increasing the infusion of seawater into the subsurface supply. In the past decade or two, plant scientists have been focusing more attention on those wild plants that thrive in oceans, estuaries, salt marshes, and other saline circumstances. Their tolerance to salt is not yet well understood, but studies of mineral and, particularly, salt transport in plants are promising.

Several agricultural plants show reasonable salt tolerance. Barley is the most salt-tolerant grain grown on a large scale, and certain wheat species exhibit some salt tolerance as do some heretofore commercially unexploited varieties of tomato. Substantial work is already being done on selection and breeding of wheat to develop strains with high tolerance for environmental stress. While only 4 of the more than 2,000 wheat species are extensively cultivated, there are over 200 wild species with growth characteristics that might be cross bred into cultivated wheat to yield more tolerant strains. Breakthroughs in plant genetics may provide a capability to engineer a wide range of crops for specific environmental conditions.

BIOCHEMICAL ELECTRONICS

Studies have found that certain biological structures perform electronic and chemical functions that can be recognized as gated channels, power supplies, pumps, sensors, and transducers. The lipid membrane of the living cell is a very thin (in the order of 5-10 nanometers) but intricate biological structure that has complex chemical and electronic properties. The characteristics of the cell membrane are coming under increasingly detailed study through the use of electron microscopy, revealing such extraordinary traits as the control of electron transfer both along and across the membrane. Scientists believe that those effects play an important role in the respiratory and energy conversion functions of living systems and in other fundamental processes. Breakthroughs in relating the microstructure of such membranes to total system characteristics and in developing techniques to selectively alter or control the membranes to produce desired effects could propel this field forward very rapidly.

COGNITIVE SCIENCE

The detailed relationship between large-scale manifestations of thinking and specific neurophysiologic activity can not yet be established, nor can the relationship between neurophysiologic activity and biochemical properties of the system. Discovering those relationships will be central to the expected rapid and exciting developments in cognitive science. Advances in that direction will have implications for the development of artificial intelligence and for advances in medicine.

Artificial intelligence research focuses, for obvious reasons, on making computers do such "smart" things as play sophisticated games or learn to make selections from a broadly defined field. But the inherent strengths of computers (speed, perseverence, precision) may not be the crucial characteristics for doing "smart" things. A better understanding of the cognitive process could lead to radical changes in the machinery of artificial intelligence.

The relationships of cognitive abilities to the environmental and nutritional influences on human beings could be particularly important in dealing with psychological disorders and in fostering high performance under stressful conditions.

POPULATION, ENVIRONMENT, AND GLOBAL RESOURCES

A variety of recent studies have predicted, on the basis of what is now known and with the continuation of current policies, a steady increase in population, particularly in already overpopulated areas; a steady degradation of the global environment; and rapid depletion of many of the world's important natural resources. Those studies have identified and documented those trends but did not propose solutions. To be effective, solutions will require not only an extraordinary degree of international cooperation and agreement but a considerably improved base of scientific information.

Some areas in need of attention include the use of remote and onsite sensing to monitor the environment and provide information for the discovery and management of natural resources; the complex interrelationships among the physical, chemical, biological, and geological aspects that determine atmosphere and ocean behavior; and the modeling of projected needs and conditions.

EARTH AND PLANETARY SCIENCES

The earth and planetary sciences are characterized by the need for extensive, sophisticated observational facilities. Satellites for viewing conditions on other planets or remotely sensing Earth's atmosphere and surface are among the most expensive research platforms, but significant studies of the oceans, Earth's crust, and atmospheric dynamics all require large investments in observational tools. Several key areas are described below.

PLANETARY ATMOSPHERES

Theories of Earth's atmosphere, which are based on observations within the atmosphere, have a limited set of facts to work with and may, therefore, be fatally flawed. The atmospheres of other planets, particularly Mars, Venus, Saturn, and Jupiter, while strikingly different from Earth's, provide cases against which general atmospheric theories or models can be tested.

An example of the usefulness of a broader perspective is the variation of mean temperature of a planet's surface from equator to pole. On Earth this variation is on the order of 15 percent and might be rationalized on the basis of the complex wind and water flow patterns governed by Earth's rotation. By contrast, the variation on Venus is only 2 percent and on Mars, 40 percent. Rotation effects seem inadequate to explain that range. Further studies suggest that the effects of atmospheric pressure on temperature mixing are important; that idea has led in turn to a better understanding of temperature variations on Earth.

In the next few years, analysis of the recent Voyager planetary probe data will provide a tremendous amount of new information on planetary atmospheres and is expected to stimulate new approaches to the general theory of Earth's atmosphere.

EVOLUTION AND DYNAMICS OF EARTH

In the last decade and a half, the crustal dynamism of Earth has become better understood. The fragmentation of the crust into plates and the phenomena that arise from plate motion and intersection continue to be studied intensively. Deep sea drilling or coring studies have been remarkably successful in elucidating the nature of the subocean crust and the sea floor. Continental crust drilling also holds great promise for providing a better understanding of Earth's evolution and current configuration.

Earth's structure has a profound influence on volcanism, earthquakes, and climate. They, in turn, greatly affect the world's societies. Although large strides have been made in the technical basis for forecasting volcanic eruptions and earthquakes, there is as yet little hope that they can be predicted precisely in the near future, let alone influenced. Nevertheless, continued systematic monitoring of volcanoes and earthquake regions, plus fundamental research into the nature of Earth's structure, could eventually provide a basis for dealing with such phenomena.

Efforts to better characterize Earth and its crust have immediate beneficial side effects. Drilling and coring activities provide information of interest to geologists searching for mineral and fuel resources. In the next decade, it is expected that a closer integration of planetary sciences and practical geological sciences will result in both a better understanding of the origins and nature of Earth and an improved ability to locate Earth's natural resources.

Since the formation of the planet, there have been important changes in Earth's rotation vector. A comprehensive model of global dynamic processes must include an identification of causal relationships for changes in Earth's polar motion and rotation rate, motions of the major crustal plates and nature of their driving forces, and accumulation and relief of crustal strains and deformations.

BIOGEOCHEMICAL CYCLES

In the last decade a great deal of interest has emerged, among scientists as well as governments, on the problems of acid rain, atmospheric carbon dioxide buildup, and fluorocarbon depletion of ozone. Those problems are all linked and are also intertwined with a variety of factors that affect the chemistry of the global atmosphere including Earth's flora and fauna, human activity, the influx of solar radiation, and the physical and chemical characteristics of Earth's surface.

The problems mentioned above are complicated by heterogeneities of sources. For example, in the case of acid rain, a significant fraction of the acid is deposited by direct dry fallout of airborne chemicals emitted by smokestacks and vehicle tailpipes rather than as a part of rain. That means that the solution must take into account not only the chemistry of the atmospheric system but the specific nature of sources and deposition patterns.

There is hope that in the next few years remote sensing will provide a better understanding of the chemistry of the cycles of carbon, nitrogen, phosphorus, and sulfur, as well as the other materials in the atmosphere (including trace metals and oxygen). With improved knowledge, the possibility of solving, or at least ameliorating, the problems of acid rain, atmospheric carbon dioxide buildup, and depletion of ozone should improve.

OCEAN SCIENCES

A mere two decades ago, oceanography was conducted in an entirely different manner than today. Then, small groups of researchers made occasional forays to gather individual measurements of such parameters as temperature and retrieved samples of water and sea floor sediments for later study. Today, ocean research is more frequently done by large teams, often international in composition. It involves far more sophisticated batteries of onsite measurements and makes use of remote sensing from airplanes or satellites.

The largest and longest concerted ocean research effort was launched in 1970 as the International Decade of Ocean Exploration (IDOE). That program, recently concluded, has produced a large amount of information on the dynamics and processes of the world's oceans and has seen the research community through an exceptionally productive and exciting time.

The next few years will probably focus both on synthesizing the vast amount of data generated by IDOE into a better understanding of the ocean system and on following up on recent exciting discoveries. For example, the newly detected hydrothermal vents in the ocean floor from which heated seawater is continually evolved and around which colonies of extraordinary plants and animals have formed could play an important role in our knowledge of the ocean life hierarchy. Satellite remote sensing will probably increase in importance for monitoring surface phenomena as well as for providing indications of deep-lying properties.

PHYSICAL SCIENCES AND MATHEMATICS

In no other field is the span of research activities or the promise of national benefit greater than in the physical and mathematical sciences. Generally, activities here find rapid application in innovative devices and processes that have an impact on the economy, in the development of techniques useful in national defense, and in providing fundamental information for many other fields of science and engineering.

ELEMENTARY PARTICLE FORCES

The number of identified elementary particles has increased from the single atom, postulated by the ancient Greeks, through the simple triad (electron, proton, neutron) of the late 19th and early 20th centuries, to the array of quarks (five types already discovered, each having three qualities), hadrons (heavy particles), leptons (light particles), and, of course, photons. Interactions among these particles appear to be of three types: strong forces, needed to explain the binding together of nuclei;

weak forces, needed to explain nuclear decay; and electromagnetic forces extrapolated from macroscopic experience.

The three types of forces seem to describe adequately the nature of interactions at distances down to about 10^{-15} cm (about 1 percent of a proton radius). That is the shortest distance probed in today's particle accelerators. While it is not known what really happens at shorter distances, it is believed that at distances of the order of 10^{-29} cm all three forces will give essentially the same results. Conditions responsible for "disunifying" the forces at greater separations have not been discovered but could provide an important clue in the search for a unified field theory.

It is hopeless to consider a laboratory experiment to probe such short distances because the energy needed is many orders of magnitude beyond what could be conceived in terrestrial devices. However, the postulated "big bang" creation of the universe implies a radius of the order of 10^{-29} cm in very early stages of expansion (in 10^{-40} seconds), and it is possible that astrophysical observations could provide information relevant to the initial unified fields in the universe. Moreover, the "disunification" of interactions at that early stage could be linked to such astrophysical questions as why the universe is made mostly of matter rather than antimatter.

GRAVITATIONAL LENSES

Einstein's general theory of relativity predicts the bending of electromagnetic radiation in gravitational fields. The phenomenon has been observed many times, for example, where light or radio waves from a distant object pass close to the Sun. Recent evidence has been found of a gravitational lens, due apparently to the presence of a massive galaxy between us and a distant quasar, that created multiple images of the quasar. Three separate optical images and two radio images were produced. Two of the optical images were quite close, and for a time it was thought that the pair was actually a binary quasar system.

The significance is twofold. First, it is extraordinary that the explanation of the twin quasars came in a time as short as the 8 months devoted to the problem. In this field, progress is usually much slower. Second, the occurrence of a gravitational lens provides further support for and clarification of the general theory of relativity but could greatly complicate the interpretation of astronomical observations, particularly of the most distant objects.

ULTRARAPID PHENOMENA

The continuing development of such experimental techniques as laser spectroscopy and molecular beams, capable of probing very rapid chemical reactions, holds promise for unraveling the progression of transition states in going from the initial reactants to the final product. Such states last for very small fractions of a second, about a nanosecond (10^{-9} sec) or less. Probing of intermediate states in a reaction gives insight into the factors that govern reaction speed and promises to help in developing analytical theoretical methods for determining not only overall reaction rates in complex systems but in identifying critical stages for control and manipulation of reactions.

MATERIALS DEVELOPMENT

The development of new materials having special optical, thermal, electrical, or mechanical properties continues. Those developments, while closely connected with improved fundamental knowledge, frequently are quite close to practical applications. Such amorphous bulk materials as glasses are being developed for particular optical and electro-optical characteristics. For example, glasses with certain ingredients can serve as optical elements with precisely engineered spectral pass bands and attenuation patterns. Amorphous semiconductors hold promise for use in inexpensive specialized electronic components. Amorphous metals are being developed and marketed with mechanical strength, corrosion resistance, and magnetizability in mind. If amorphous metals were used as transformer cores in residential power distribution systems, power losses of the order of $500 million per year might be avoided.

Knowledge of material surfaces is key to understanding such phenomena as corrosion and catalysis. The improved ability to study the properties of electrons ejected from surfaces by light or X-rays reveals much about the chemical and physical structure of the surfaces and the materials interacting with them.

Political pressures that affect the Nation's supply of critical materials are driving research both into new techniques for recovering available resources and into development of replacement materials having equivalent properties for specific applications. Ion-beam implanting of substances that cannot be mixed chemically is yielding materials with desirable properties that can replace certain critical materials whose supply is threatened.

ENGINEERING SCIENCES

The reinvigoration of the engineering sciences and the vastly increased demand for engineers bear witness to the promise of this area for improving the strength and welfare of the Nation. Engineering affects virtually every segment of society, and ultimately the solutions to society's problems will rest on our engineering abilities.

ROBOTICS

Automated manufacture may help solve industrial productivity problems. Robots (computer-controlled machines) have successfully replaced human workers for such unpleasant or dangerous jobs as painting and spot welding. Recent progress in the development of visual and other sensors, as well as improvements in control language, promises much wider use of robots in ever more complex functions. However, widespread use of the robot is still constrained by the need for better computer programs, improved communication, sensors, and mechanical flexibility. Today's robots are slow and limited, but development is rapid, and the time when the robot may successfully compete on a large scale with human workers in such complex activities as parts assembly may not be far off. It would be advantageous for the United States to pursue robot technology aggressively to maintain a competitive edge in industries likely to manufacture and use robots. The use of robots will relieve workers from monotonous and dangerous jobs, while opening up new career fields in robot industries.

MICROENGINEERING AND MICROSTRUCTURES

New techniques for generating ultrasmall (about 50 atoms across) features on materials have been developed and promise a new generation of microengineered electronic components. This is another step toward the goal of constructing electronic systems on the macromolecular scale.

Optical technologies are making inroads in digital computing. They offer higher densities of information, more rapid computing, and advantages in storage, display, and transmission of data. The blending of optical technologies and more conventional electronics at the microstructure level promises a new generation of devices that will be useful in computing, communications, control, and information handling. The ability to engineer structures on a smaller scale increases the degree to which specific electronic or electro-optic components can be crowded onto a small chip. Very large scale integration of such components promises to make sophisticated capabilities both affordable and convenient enough for mass markets.

INFORMATION TECHNOLOGIES

Since 1959, when integrated circuits were first introduced, microcomputer densities have doubled yearly; reliability, every 2 years; and operating performance, every 3 years. The costs of processing and storing information have fallen at a similar pace. In telecommunications, the channel capacity of a single communications satellite has doubled every 2½ years since the first such satellite was launched in 1965, while the required investment has declined at roughly the same rate. Recent advances in processing and storage mean that the costs of computer-based communications are virtually independent of distance, and that multiple users need not use the same circuit at the same time.

Fiber optic cables that can carry thousands of voice circuits are now possible, and they cost substantially less than copper cables. As an information carrier, light has far greater capacity than lower frequency radio waves. Optical systems offer the promise of higher speed, finer resolution, and, for certain applications, more efficiency than current systems. Advances are coming in the development of sensors (character readers, for example) and pattern recognition and output devices (priniers, for example). As transmission lines, optical fibers are steadily being improved in their fidelity and power transfer characteristics. Great strides are being made in the development of optoelectronic elements (devices combining optical and electronic signals) to perform such functions as modulation, amplification, logic, and information storage.

Information science and technology have an important global dimension. Transnational data flows and their relation to questions of privacy and proprietary interests form an important international concern. Many countries now participate in UNESCO and other intergovernmental activities in the field of "informatics." In the last 3 or 4 years, there has been an increasing effort, particularly by developing countries, to establish international principles for the "New International Information Order" that would, among other things, give governments control over news media, a notion unacceptable to the United States.

LASER TECHNOLOGIES

The improving ability of lasers to deliver radiant energy of relatively high spectral purity and either short pulse or continuous duration is opening new avenues of research into the mechanisms of chemical reactions and the structure of molecules. As a research tool, the laser is becoming more widespread in use and, in many cases, less expensive.

There are commercial applications for lasers in a variety of areas, including telecommunications, where optical systems use laser repeaters in fiber optic transmission lines; in medicine, where laser surgery, particularly on the intricate anatomy of eyes and ears, allows results not possible a few years ago; in manufacturing, where laser heat treating, annealing, and cutting operations are more precise and controllable than more traditional methods; and in control applications, where precise sensing (for example, location of a device or presence of contaminants in a region) is needed to actuate a response.

In the near future, new lasing materials, new methods of storing energy in lasers, and new techniques for inducing and controlling the lasing process are expected to continue expanding the realm of utility for lasers in general. The free-electron laser, which is essentially an electron beam interacting with an optical beam, has high intensity and is tunable across a wide spectrum, from microwave frequencies into the ultraviolet. As a tunable laser, it holds promise for improved laboratory investigations and is a prime candidate for a high-energy laser. The carbon dioxide waveguide laser is being developed rapidly and promises extremely long life (10,000 hours) and long shelf life (several years) in the near future.

6 Natural Resources*

HIGHLIGHTS

- The world's tropical forests are disappearing rapidly as expanding populations seek wood to burn, raw materials, and land for agricultural uses. Among the serious direct consequences are increased floods, water shortages in dry periods, expanded desert areas, extinction of indigenous plant and animal species, and the possibility of both short- and long-term climate impacts. A Federal interagency task force has assessed the problem and recommended solutions both domestically and internationally.
- The allocation and distribution of scarce domestic water resources, particularly in the western United States, must be confronted and solved. The need for water in the development of western synthetic fuels (oil shale specifically) will compete with the requirements of agriculture and of urban populations.
- Irrigation, cropping, and grazing on arid lands have led in some instances to inadvertent degradation of fragile areas in a process known as desertification. A national assessment under the direction of the Interior Department's Bureau of Land Management and with the cooperation of the Department of Agriculture and other Federal and State agencies will describe the dimensions of the problem, causative factors, and successful technologies to prevent and overcome the effects of desertification.
- Satellite remote sensing technology is being used increasingly for management of natural resources and exploration of nonrenewable resources. The decision has been made at the Federal level to convert the Landsat remote sensing system from an experimental to an operational mode; that should be achieved by the end of this decade.
- Achieving better capability to provide early warning of natural disasters (floods, volcanic eruptions, earthquakes, hurricanes, and tornadoes) is one of the major objectives of science and technology research.
- Potential interruptions of supplies of some imported strategic nonfuel minerals (chromium, cobalt, platinum, manganese) could impede defense production and damage the U.S. economy. Efforts must be made to lessen the danger through changes in mineral policy and better targeted research programs.
- Ocean nodules could be an important future source of cobalt, nickel, and manganese. Recent Federal leg-

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[*] Participants in the task group developing this section included representatives of the Department of the Interior, the National Aeronautics and Space Administration, the National Oceanic and Atmospheric Administration in the Department of Commerce, the Department of Agriculture, and the Department of State.

islation establishes an interim procedure for orderly development of mineral resources in the deep seabed until an international regime can be developed.

- Plans have been developed for conserving and managing marine fishery resources off the coasts of the United States. Hydroacoustics technologies and satellite and aircraft remote sensing provide opportunities for enumerating fish populations and learning how changes in the marine environment (from pollutants or climate patterns) affect the oceans' living resources.

INTRODUCTION

Throughout history there have been instances of the misuse or overexploitation of Earth's natural resources, the raw materials on which our highly complex society is based. In the United States, the concept of conservation of natural resources began at the turn of the 20th century, and by now most societies accept the premise that natural resources must be developed with appropriate safeguards. How to do that and still meet society's ever-increasing needs has become a major challenge for most governments.

A fundamental question that must be posed in any discussion of natural resources is their finiteness. Some analysts are concerned that our civilization's growth rates may be limited by the availability of natural resources, whereas others feel that science and technology will be able to solve any resource availability problems. Science and technology certainly have an important role to play in the management of, the conservation of, and the search for alternatives for our natural resources. It is toward the opportunities and challenges presented by that role that Federal research efforts must be directed.

TROPICAL FORESTS

Forests are among man's most valuable renewable natural resources and are vital to economic development. They provide many useful products and also are of great importance to the environment since, for example, they have a regulating effect on stream flow and lessen soil erosion. In the past few decades one of the most serious international environmental problems has been the increasing devastation of the world's tropical forests. Several international conferences have examined the problem, and the consensus is that concerted programs by the international community must be launched to prevent the destruction of a major portion of the world's tropical forests over the next three or four decades. A U.S. Interagency Task Force on Tropical Forests consisting of representatives of 12 Federal agencies recently concluded "the world's tropical forests are indeed in jeopardy, and that serious social, economic, and environmental costs are being incurred [by forest devastation]—particularly by rural populations in tropical developing countries. . . [and] the task force firmly believes that the U.S. efforts, meshed efficiently with those of other nations and international organizations, can make a difference." The task force also noted that the loss of tropical forests is due principally to the large-scale conversion of forest land to other uses, mainly agriculture.

Major consequences of tropical forest loss are: (1) destruction of the way of life of the indigenous peoples in forest areas; (2) disappearance of a considerable proportion of the world's tree and plant species, many of which have not been identified; (3) disappearance of much of the remaining wildlife; (4) loss of many new genetic resources that might be exploited to provide new foods, medicines, textiles, and even fuels; (5) increased desertification; (6) increased erosion and flooding; (7) lessened water availability; (8) worsened carbon dioxide (CO_2) release problem; and (9) loss of the forests' capacity to provide useful products on a substantial basis.

The U.S. Interagency Task Force on Tropical Forests submitted its report in mid-1980 with recommendations for a policy, strategy, and program. In its report, the task force acknowledged that the United States cannot establish goals for other countries, but that it can identify important goals that are likely to be in harmony with those that most other countries would develop. Among the major short-term goals recommended were (1) the initiation of an internationally coordinated action program on tropical forest research, monitoring, training, education, and information exchange; and (2) the doubling of the worldwide rate of reforestation and afforestation.

In July 1980, when the *Global 2000 Report to the President* was released, all Federal agencies were directed to respond to recommendations made by the Interagency Task Force on Tropical Forests by detailing the steps that they would take to implement the recommended programs. The principal natural resource management agencies involved are the Forest Service in the Department of Agriculture; the Bureau of Land Management (BLM), the National Park Service (NPS), and the Federal Wildlife Service (FWS) in the Department of the Interior; the National Oceanic and Atmospheric Administration (NOAA) in the Department of Commerce; the National Aeronautics and Space Administration (NASA); the National Science Foundation (NSF); the Department of State; the Agency for International Development; and the Smithsonian Institution. An assessment of their existing programs in tropical forestry is under way, and new initiatives are being planned. Over the next 5 years tropical forestry will receive increasing attention at all levels and will require greater science and technology support.

WATER RESOURCES

Water and related land resources issues have been the focus of 18 major pieces of Federal legislation during the last several decades. The most recent was the Water Research and Development Act of 1978 (Public Law 95-467). Major Federal water R&D programs exist in the Department of the Interior, the Environmental Protection Agency (EPA), the Department of Agriculture, and the Corps of Engineers, with smaller programs in the Departments of Transportation, Energy, and Commerce, and NASA, NSF, and the Tennessee Valley Authority (TVA). Under the 1978 Act, the Secretary of the Interior was directed to develop a 5-year Federal water resources program in cooperation with the 54 State and territory research institutes. This was a major program element in the Department of the Interior's Office of Water Research and Technology (OWRT), which will no longer be funded as a separate bureau.

Dwindling or contaminated supplies of fresh water in many areas of the country have led to increased research on the uses of saline water. The technology for converting seawater, brackish water, and other contaminated water to useful quality has now reached the demonstration stage, and during 1980 three sites were considered for water desalting plants (Alamogordo, New Mexico; Virginia Beach, Virginia; and Grand Isle, Louisiana). All three plants would use different desalting processes. In the next few decades, extensive use of desalting technology should contribute to solving the problem of the increase in mineral content in water as it undergoes cycles of use and treatment. The drinking water standards of the United States specify a safe level of total dissolved solids of 500 ppm for potable water; many of the Nation's water supplies do not meet the standard. The Safe Drinking Water Act broadens the scope of Federal regulating authority to include all public water supplies with 15 or more connections or serving 25 or more people. Bringing all drinking water up to standard by the year 2000 will require that about 11 billion gallons per day receive some form of desalting.

To minimize duplication of effort and facilitate dissemination of data, the Water Resources Division (WRD) of the U.S. Geological Survey (USGS) has been made the agency for coordinating the water data acquisition activities of all Federal agencies. In addition, WRD cooperates with almost 750 State and local agencies on a 50-50 cost basis. The science and technology aspect of WRD's research has as its goal the development of sufficient understanding of hydrologic systems to permit quantitative evaluation of the response of these systems to either natural or manmade stresses.

ARID LANDS

Desertification is the sustained decline and/or destruction of the biological productivity of arid and semiarid lands. A variety of ecological changes destroy the vegetative cover and soil fertility in arid and semiarid lands and lead to such problems as vegetation loss, loss of plant variety, brush invasion, loss of animal population, decline in yield, erosion by wind and water, nutrient loss, compacting and crusting, salinization of soils, water logging, water salinity buildup, and sedimentation.

About one third of the total world land area is arid, and it supports about one seventh of the world population. United Nations studies have identified about 2 billion acres worldwide where there is risk of future desertification, some 2½ times the area now classed as desert. A major federally guided U.S. study of desertification is under way. The study is coordinated by BLM, which has the management responsibility for western public lands. This is the first major attempt in the United States to assess the issue of desertification.

In addition, the following activities are under way:

(1) The U.S.-Mexico Agreement on Arid Lands Management and Desertification Control, signed in February 1979, setting up a joint work program to combat desertification in the border zone and to conduct state-of-the-art research in a number of areas;
(2) U.S. membership in the Consultative Group for Desertification Control formed by the United Nations Environment Program (UNEP) to assess proposed desertification control projects;
(3) Expansion of our bilateral development assistance programs in areas related to desertification, including energy alternatives to firewood, support for the Sahel Development Program, reforestation and remote sensing applications in arid lands, and desertification monitoring and assessment; and
(4) Expansion of U.S. research in such areas as salt- and drought-tolerant plants, commercial development of various arid lands plants, new technologies and management techniques for watersheds and rangelands, and improved techniques for water harvesting.

The United States and Mexico, in concert with UNEP, are planning cooperative activities in three key areas addressed by the Global Plan of Action: desertification monitoring, cost-benefit methodologies as applied to desertification, and food-climate relationships in arid lands.

There are numerous opportunities for science and technology contributions to alleviate desertification. They include design and funding of research and development on salt-tolerant crops and vegetative covering, greater economic use of naturally occurring arid plants, rehabilitation of degraded lands, use of saline water in agriculture, introduction of operational desertification monitoring techniques, and management of surface-water and ground-water reservoirs. Coordination of domestic and international efforts in those areas is a major challenge to the United States.

REMOTE SENSING OF NATURAL RESOURCES

As a natural outgrowth of the major U.S. space programs, plans were conceived in the 1960s to survey Earth's natural resources from a space platform. That resulted in the experimental Landsat series of satellites (earlier called ERTS), the first of which was launched in July 1972. Since that time two additional Landsat satellites have been launched, and over 100 nations are applying the resulting experimental data to resource management problems of all types, ranging from monitoring the movement of icebergs in the Arctic to classifying land use patterns in urban areas. Specific applications of Landsat data include surveying soils; estimating crop acreage and yields; measuring timberlands, rangelands, and water resources; mineral and oil exploration; land use planning; health and environmental protection; population estimation; monitoring nonliving marine and coastal resources; and disaster warning and assessment.

Because of the success of the experimental program, the Federal Government decided that Landsat would become an operational system. In November 1979, NOAA was assigned management responsibility for civil satellite remote sensing operations in addition to its ongoing oceanic and atmospheric responsibilities.

The move to an operational satellite system is to take place in the 1980s. At present, there are four major Federal agencies (NASA, NOAA, and the Departments of the Interior and Agriculture) cooperating directly in the Landsat program and sharing the operating and information disseminating responsibilities. Launch of the fourth satellite in the Landsat series, Landsat D, is scheduled for the fall of 1982. Landsat D is scheduled to fly a new sensor called the Thematic Mapper, which has a 30-meter ground resolution as compared with the present Landsat sensor, the multispectral scanner, whose resolution is 80 meters. There are presently Landsat ground receiving stations in Argentina, Australia, Brazil, Canada, Union of South Africa, Sweden, Italy, India, and Japan with similar stations planned for China, Thailand, and Upper Volta.

NATURAL HAZARDS

Such natural hazards as hurricanes, floods, earthquakes, tsunamis, and volcanic eruptions threaten and frequently cause extensive damage to life and property. One of government's responsibilities is to minimize the damage by providing adequate warning for imminent natural disasters. Further, it is the mission of the scientists involved in natural hazards research to continually try to improve their predictive capability. The value of such predictions was vividly illustrated with the violent May 18, 1980, eruption of Mt. St. Helens. As one writer observed, "The great demolition of the top of a mountain is a dramatic reminder that a rare event known to be possible, but highly improbable, can occur here and now. . . . Mt. St. Helens underlines the need to keep the extreme occurrence in mind. It further enhances respect and sympathetic understanding for scientific forecasts of natural hazards." Under legislation passed in 1974, the USGS has the responsibility to warn State and local officials of impending geological hazards. In the case of severe weather and flooding, it is the National Weather Service that must provide warnings. Extensive research facilities in both agencies are continuously conducting research to improve predictive capability.

To enhance our predictive capability in weather forecasting over the next 5 years, modeling techniques should be developed to use satellite, radar, and conventional data to predict localized flash floods, tornadoes, hurricanes, and landfalls. Also, to improve the scope and accuracy of weather forecasting, improved global observational systems and better regional and global prediction models should be designed. Integrated systems using new techniques must be developed for handling environmental data and transmitting it to users. Voice-synthesis and information systems for use in conjunction with such systems as cable TV are under consideration.

Among natural hazards, earthquakes pose the greatest single-event geological hazard, and, in the United States, southern California's urban regions have the highest potential for disaster. Because of the sudden and devastating nature of earthquakes, scientists are continuously striving to develop better methods for predicting them. Japan initiated a prediction program in 1965, and Soviet scientists have been working on similar programs for many decades. By the mid-1960s, Soviet researchers had made several significant contributions to predictive ability when they determined that prior to some earthquakes, the speed with which seismic waves pass through the earth show a distinctive trough-like wave pattern and the release of radon gas increases; further, the electrical resistivity of the earth behaves strangely before certain earthquakes. Following several major quakes in 1966, the Chinese also began a major program, and an estimated 10,000 scientists and technicians are working on earthquake research. Over 10 earthquakes have been predicted successfully, but many more have not been predicted.

U.S. scientists have observed such additional precursors as the changes in the Earth's magnetic field prior to a quake in November 1974. In one of the few cases of a precise prediction, a U.S. Geological Survey employee informally predicted a 1974 Thanksgiving Day earthquake on a small fault near the famous San Andreas fault. Commenting on the present state of the science of earthquake prediction, a leading Federal scientist said,

> Theoretical, laboratory, and field studies have confirmed that earthquakes are not single ruptures of the rock but are made up of complicated series of rupture starts and stops. Field measurements and seismological studies have provided independent and compelling evidence that many earthquakes can occur in a low stress environment. We have established procedures for estimating damaging ground motion from earthquakes and reliable methods for specifying the uncertainty in these measurements.

NONFUEL MINERALS

The United States currently is heavily dependent on imports from foreign countries for its supplies of several critical mineral commodities, such as chromium, manganese, cobalt, and the platinum group metals, which are important to both industrial and national security objectives. In a time of great world tensions, those supplies are not secure, and the Nation must be prepared for potential supply interruptions. In recognition of that problem, President Reagan, early in his administration, initiated the first purchase program for the national defense mineral stockpile in over 20 years. As a further step in developing a national minerals policy, the President initiated a major review of minerals policy under the direction of the Cabinet Council on Natural Resources and Environment. Among the working groups of this Cabinet Council is the Strategic Minerals Working Group, which includes representatives of all Federal agencies whose activities are related to the availability of these mineral commodities. This working group will identify the most urgent problems, will consider implementation of Public Law 96-479, the "National Materials and Minerals Policy, Research and Development Act of 1980," one component of which is to increase mining and metallurgical research efforts, and will examine in depth the critical mineral bottlenecks which potentially could impede defense mobilization and seriously affect vital manufacturing industries.

DEEP OCEAN MINERALS

One potential mechanism to counteract eventual interruptions in the supply of critical minerals is to seek additional supplies in the ocean floor. Over the past several decades, U.S. industry has reportedly spent over $200 million in developing the technology to mine such mineral sources as nodules from the ocean floor of the Pacific, the richest area being south of Hawaii and west of California.

Similar manganese nodules are also found at shallower depths off the Florida-South Carolina coast in what is known as the Blake Plateau. The nodules, similar in size and shape to potatoes, contain nickel, cobalt, and manganese—all minerals important to our economy and nearly all of which must be imported. Cobalt is particularly critical since our primary source is Central Africa, an area subject to possible unrest. There is considerable international interest in deep-ocean mining, with Japan, West Germany, France, and the Soviet Union all participating in projects supported by their governments. Among those nations, the Japanese, the West Germans, and the French have been the most aggressive in trying to achieve commercial production. For example, 30 Japanese firms have formed a Deep Ocean Mining Association.

Major U.S. industrial firms have combined resources with foreign firms to develop the expensive technology required to mine the nodules from the ocean floor at depths of about 3 miles. Most U.S. groups feel that their technology has advanced to the stage where commercial operations could begin in the early or mid-1980s at anticipated costs of $1.0 billion or more for each group. In earlier years one of the main deterrents to mining was lack of international agreements or domestic laws for guaranteed mining site tenure at specific locations. The first attempts to develop an international regime began in 1973 when the United Nations began conferences on the Law of the Sea, which was to determine the guidelines for development of seabed resources. To date, no agreement has been reached. To provide the U.S. international industry with incentives to proceed, the Deep Seabed Hard Mineral Resources Act (Public Law 96-283) was signed on June 28, 1980. It established interim regulatory procedures for U.S. ocean mining activities under the administration of NOAA. The act recognizes that the resources of the seabed are a common heritage and requires that revenues from commercial production be set aside for developing countries.

In Section 109(a)(2) of the act, a 5-year program is mandated for ocean research to provide environmental assessments during the exploration and commercial stages of seabed development. The research is to include ecological, geological, and physical evaluations of the seabed where mining or processing activities may take place. Life histories of plants, animals, and organisms of ocean areas that may be affected will be studied. The research plan is being prepared by NOAA for submission to Congress.

MARINE FISHERY RESOURCES

Passage of the Fishery Conservation and Management Act of 1976 (FCMA) has called for the development and implementation of plans and regulations to conserve and manage U.S. fishery resources within the fishery conservation zone extending from 3 to 200 miles off the coasts of the United States and its possessions.

Management and conservation measures under FCMA depend on the best attainable estimates of the abundance and condition of fish stores in each commercial fishery. Such annual yield projections rely not only on the determination of presently harvestable fish within each fishery, but also the assessment of preharvestable juveniles, the prey-predator competitive interactions between species, and of pollutants, changing oceanographic conditions, and long-term climatic changes. The primary information used to date has been largely derived from conventional stock assessment surveys and catch statistics. However, extensive research is being directed toward improving such assessments. It includes studying the application of the rapidly maturing technologies of hydroacoustics to enumerate fish populations and satellite and aircraft remote sensing to describe the spatial and temporal variation of marine environmental properties impacting on the oceans' living resources. As suitable data bases and real time data inputs become available, they are being used to develop numerical models describing the population dynamics and yields of both single species and multispecies fishery resources.

A variety of research efforts centering around the effects of habitat alteration and degradation on the productivity of living marine resources will also be important in fulfilling the national mission. The specific habitat requirements of important commercial and recreational fishes must be known to predict the extent to which habitat destruction or degradation can occur before productivity is impaired. Improving predictive capabilities of long-term pollution effects, especially for low-level, chronic exposures to multiple pollutants, will be needed in determining the assimilative capacities of estuarine, coastal, and shelf environments. Also of increasing concern are the future effects on living marine resources of the diversion, to meet human needs, of fresh waters of rivers that feed estuaries.

Aquaculture affords the opportunity to greatly supplement the production of shellfish harvested from natural ocean populations, many of which are being fished at near maximum sustainable yield levels. An expanded scientific and technological base will place the United States in a better position to meet anticipated needs for increased fishery production. Through genetics, selective breeding, and hybridization, for example, fish farmers should be able to develop faster growing, disease-resistant species of fish and shellfish that exhibit better feed conversion ratios and improved processing characteristics.

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7 Environment*

HIGHLIGHTS

- Refinement of the methods to be used for the control and disposal of hazardous wastes is now being sought in response to increasing volumes of waste and public concern about their safe handling. Identification of suitable long-term disposal methods and sites is a high priority.
- Pollution of the environment by toxic chemicals and as a result of energy production is a problem of great national concern. Minimization of pollution sources, assessment of adverse health and environmental effects, understanding of Earth's ecosystems, and development of appropriate control measures are integral parts of pollution management. Accurate and timely information can help guide policymakers in designing pollution control strategies.
- Acid precipitation, resulting in part from the use of fossil fuels, and its potential effects are of growing national and international concern. A coordinated research program has been initiated to increase understanding of the problem.
- Pesticide use is prevalent both in agricultural and in urban areas. A better understanding of adverse health and environmental effects is vital. Integrated pest management may help minimize the introduction of pesticides into the environment.
- Critical problems exist in maintaining the quality of the Nation's water supply. Efforts to clean up problem areas must be matched with the development of quality standards and control strategies. Extensive studies of ground-water contamination are planned.
- Climate has a major influence on energy consumption, agricultural production, and water resources management. Research activities cover basic understanding of climate, impact of climate fluctuations, and forecasting.

INTRODUCTION

Environmental research programs provide scientific information that serves, in addition to increasing general knowledge, as a foundation for the formulation, implementation, enforcement, and review of environmental standards and regulations. To facilitate the use of the information, Federal research programs are organized either along the lines of regulatory programs or in a manner that consolidates research functions to promote the most effective data production, analysis, and interpretation. Some programs are organized by pollutant type (hazardous air pollutants, pesticides), while others deal with specific problems (energy, nuclear wastes). Throughout, however, three factors provide the framework within which the research is conducted:

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*Participants in the task group developing this section included representatives of the Environmental Protection Agency, the Department of Energy, the Department of the Interior, the Department of State, the National Aeronautics and Space Administration, the National Oceanic and Atmospheric Administration in the Department of Commerce, and the Nuclear Regulatory Commission.

(1) To meet near-term needs, the most accurate, complete, and scientifically credible research data must be provided. The information, since it often spawns controversy, must ultimately be able to withstand close scrutiny or legal challenges so that environmental standards and regulations meet the goals set by the American people to protect human health and welfare, environmental quality, and the overall quality of life.

(2) To meet long-term needs and emerging or anticipated environmental problems, support for fundamental and anticipatory research in the basic sciences is necessary. Such research will enable us to gain a better understanding of the causes and consequences of problems before they become acute and to find means to eliminate, mitigate, or control the problems before serious damage is done to the populace or the environment.

(3) Environmental research in support of regulatory programs must carefully estimate the costs and benefits of environmental quality that result from controlling—or not controlling—harmful pollutants. It is the primary responsibility of researchers to identify and quantify the risks that hazardous exposures (in whatever form) pose to man and the environment and to estimate the comparative costs and benefits of regulatory actions designed to establish limits for those exposures. Policymakers then incorporate these research results into essential economic comparisons for controlling or not controlling pollution in order to keep the environment safe and productive at the lowest possible cost.

This three-part research framework has remained relatively constant over the past 5 years; however, the focus of the research itself has not. In upcoming years, priorities will shift from the more traditional areas of research to other, newer areas. Part of the shift will result from the maturation of traditional programs, but the major change will be due to the recognition of serious threats to the health of the American people and to the environment from solid and hazardous wastes, toxic substances, and contamination of ground-water sources of drinking water. In the next few years the highest priority for research will be given to characterizing the threats from these pollution problems, defining their dangers to health and the ecological balance, and, if possible, developing, testing, and evaluating means to control the pollution. A summary of the research programs dealing with these and other problems is presented below.

SOLID WASTES

Public awareness of the threat that hazardous wastes pose to health and safety has grown recently because of such highly publicized problem areas as Love Canal. Improperly disposed of wastes have been cited as possible causes of serious health effects (for example, cancer, birth defects) that do not appear until many years after disposal occurs. Government response has two primary goals. First, a national strategy for managing the estimated 57 million tons of hazardous wastes that current industrial processes yield will be set in motion. Second, existing problem hazardous waste sites, numbering as many as 2,000, must be carefully investigated and steps taken to contain their contents.

Those goals can be met only with considerable scientific and technological support. Specific research data are needed to identify hazardous waste sources and types of waste threats at those sources, quantify hazards and provide technical expertise for controls at restricted hazardous waste sites, develop technologies to protect people from the effects of hazardous wastes, assess risks from hazardous wastes to health and the environment, verify which energy and mineral wastes are hazardous, and develop means to dispose of and recover resources from nonhazardous wastes so they may be eliminated from possible hazardous waste consideration.

Three research approaches will be employed to provide the critical information. The first approach is to reduce the quantity of certain hazardous wastes at their point of origin by developing new, economically feasible industrial production processes or improving old ones; finding or developing substitute materials for those that cause or contribute to hazardous solid waste; and increasing product durability, thereby reducing waste generation. The second research approach is to find means to transport, store, treat, and dispose of those industrial wastes for which there are no currently acceptable means of elimination or recovery. The third approach is to develop methods to remove and recover hazardous materials from waste streams during waste disposal operations. The goal is not for recovery and reuse but, rather, for reducing exposure of the public and the environment to hazardous substances.

As data are accumulated, solid waste research will help protect public health and environmental quality. Furthermore, because some of the research focus is on eliminating the cause of solid waste before it is produced, the research will also promote resource conservation, materials reuse, and energy recovery.

TOXIC SUBSTANCES

The development of modern industrial society has been accompanied by a proliferation of chemicals for all kinds of applications. While chemicals are very useful for specific purposes, there are risks involved with the use of some because of the harmful physiological effects that can result. Exposure to some chemicals, even in small amounts, can lead to such irreversible biological effects as cancer, genetic damage, and birth defects. As a result, environmental legislation (especially the Toxic Substances Control Act of 1976) has sought to protect public health by controlling toxic substances in commerce.

Research is needed to identify and assess the health and environmental risks posed by production and distribution of certain chemicals. Of first concern is the development of suitable tests to evaluate adverse effects; tests to predict hazards to humans are particularly needed. Near-term research will revise and expand current test methods and will standardize the testing of a chemical's characterization, fate, and effects. As such test methods are established, hazardous materials can be identified before their introduction into the environment.

In addition to developing tests for determining the adverse health and environmental effects of toxicants, the research will develop testing and assessment requirements for chemical monitoring and control. Then, as discharges of certain chemicals slow or stop, the research will provide data for implementation of regulations and enforcement.

Health effects research will attempt to arrive at the best possible assessment of a chemical's ability to produce or exacerbate human diseases. Assessments will include descriptions of a range of diseases that can result from exposure to a toxicant, the appropriate means to detect chemically induced processes, the body's basic and critical factors that are affected by a chemical, and comparisons of human sensitivity to the chemical with the sensitivity of test species. In focusing on environmental effects, research will be directed toward developing testing and assessment methods to correlate information on the production, use, and disposal of a chemical with data on its physical, biological, ecological, and chemical properties. For monitoring research, techniques will be developed for analyzing pollutants on a media- or matrix-specific basis, for obtaining samples by biological matrix (for example, tissue, blood), medium, or pollutant, and for finding a best single method that can be used to identify and quantify a wide range of pollutants.

ENERGY AND ENVIRONMENT

Energy use projections indicate a trend away from such relatively clean sources as onshore oil and gas toward such potentially more environmentally damaging fossil fuel sources as coal, oil, or gas from the Outer Continental Shelf, and western oil shale. Increased extraction, processing, and use of less clean fuels may pose threats to the environment and to human health.

A problem currently causing great national and international concern is acid precipitation, caused in part by emissions from fossil fuel power plants. Pollutant emissions, particularly sulfur dioxide and nitrogen oxides, may be contributing to increased acidity of precipitation, often many miles from the source of pollution. Environmental effects attributed to acid precipitation include damage to lakes and streams and potential harm to forests, rangelands and wildlife, crops, soils, materials (for example, monuments, buildings), and drinking water.

One constraint on resolving the problem of acid precipitation is that there is little known about the precise relationships between fossil fuel use and acid precipitation and about the real effects of increases in such acidity. In order to increase that understanding, the National Acid Precipitation Program, established by Public Law 96–294, mandates comprehensive and accelerated research on the causes and effects of acid precipitation. The statutory Interagency Task Force on Acid Precipitation, responsible for planning and implementing the program, is jointly chaired by the Environmental Protection Agency (EPA), the National Oceanic and Atmospheric Administration (NOAA), and the Department of Agriculture (USDA). The program includes research on sources, atmospheric processes, impacts, control strategies, and monitoring activities; the primary goal is to provide a better information base for establishing sound energy and environmental policies.

Energy and environment research programs conducted by EPA and the Department of Energy (DOE) (including research on acid precipitation) provide a scientific rationale for policies that balance health protection, domestic energy supply factors, cost, and environmental quality. The programs are divided into two major research areas: health and environmental effects, and control technology.

Research in health and environmental effects focuses on three areas: the identification of energy-related pollutants in the environment, the mechanisms by which those pollutants move through the environment, and their resulting effects on humans, animals, and plants. Control technology research provides information on pollutant types and quantities released by activities to supply energy and develops or stimulates the development of cost-effective control options. The control technology research will also produce technical data and cost information upon which environmental standards will be based. Emphasis will be on information supporting the establishment and implementation of technology-based environmental guidelines that minimize environmental damage from energy fuels and processes.

EMERGENCY SPILLS

By virtue of their high visibility and potentially catastrophic effects, spills of oil and hazardous substances are currently receiving attention at all levels of government as well as in the private sector. While the total number of spills is unknown since many go unreported, at least 15,000 spills occur annually in the United States.

Spills generally contaminate the air, land, and water, rapidly spreading and dispersing into the atmosphere, soil, and surface or ground water. As a consequence, the problems they pose can be extremely diverse and involve a multidimensional matrix of substance spilled, volume spilled, location and condition of the spill site, weather, and a host of other factors.

Among the key questions that researchers will try to answer are:

(1) How clean is clean? Given the assimilative capacity of the environment and economic considerations, those who respond to spills require a mechanism to determine when one is sufficiently "cleaned up."
(2) How can biologically damaged ecosystems be repaired, and how long does the repair take? Techniques must be developed to reverse and mitigate damaging spill effects in a timely manner.
(3) What are the fate and effects of spilled materials? A scientific determination of cleanliness must be made, not one based on engineering judgment.
(4) What initial actions are to be taken at a spill site? Firemen and other first-on-scene nontechnical response personnel must know the proper emergency actions.

In response to these questions, the spills research program will develop, evaluate, and demonstrate new or improved equipment, systems, and techniques to prevent, detect, identify, contain, control, remove, clean up, or recover spills of oil and hazardous polluting substances. The program's objective is to accomplish those tasks while ensuring that every precaution is taken to protect human health, water, land, and air from any type of accidental release of hazardous materials, and that cleanup operations employ only the most environmentally sound methods. The hardware and techniques developed will be carried beyond the prototype stage to the point where they are ready for field implementation by the commercial community.

Furthermore, the longstanding emphasis on cleanup equipment will be augmented by a new emphasis on the search for a better understanding of the interaction between spills and the environment. Future research trends will be influenced by an expected increase in the number of spills, a projected decrease in the availability of disposal sites, the possible requirement that affected areas be returned to prespill conditions, an increased emphasis on the use of dispersant technology offshore, and the use of genetic research to provide microbial agents to aid cleanup.

HAZARDOUS AIR POLLUTANTS

The top priority of hazardous air pollutant research is to identify, evaluate, and control airborne carcinogens. Specifically, the research will support implementation of policies and legislation designed to control the emissions of such carcinogens. That emphasis is due to the high incidence of lung cancers and the fact that there is a great deal yet to be understood about the cause and effect relationships between those cancers and long-term, low-dose exposures to pollution. Research will therefore focus on the identification, screening, and preliminary carcinogenicity assessment of high-production, volatile organic chemicals. More detailed assessments of those chemicals that show a high potential for carcinogenicity will be developed.

Research results must be able to be used to inform policymakers where such compounds are found, in what concentrations, and where they come from. The principal thrusts for the overall research effort, therefore, will be to characterize ambient air, emissions, and sources.

Objectives in ambient air studies are to characterize the abundance and variability of toxic organic chemicals in urban environments, investigate and assess the atmospheric fate of the toxic organics, and determine the extent of human exposure to airborne toxic chemicals. Source characterization research will develop source sampling and analytic techniques that adequately separate and characterize airborne emissions of potentially hazardous materials. Comprehensive environmental assessments will be prepared for industrial point sources, fugitive emissions, conventional combustion sources, and emerging coal conversion technologies.

Research is being conducted on indoor air pollution. Developments include:

(1) Discoveries that such hazardous air pollutants as radon, residential pesticides, asbestos, benzo(a)pyrene, formaldehyde, and other organic compounds exist indoors as well as outdoors;
(2) Increasing indications that indoor concentrations of such conventional air pollutants as carbon monoxide, nitrogen oxides, and respirable particulates often equal or exceed outdoor concentrations; and
(3) Concern that intensive use of such energy conservation measures as insulating, weatherstripping, and caulking may reduce building ventilation and increase indoor concentrations of pollutants having indoor sources.

In light of those developments, research on indoor air pollution must focus on defining the extent of the problem and on identifying control options available to attain acceptable air quality.

GASEOUS AND PARTICULATE AIR POLLUTION

Such air pollutants as sulfur dioxide, particles, nitrogen oxides, and ozone are subject to a complex series of reactions, transformations, and transport processes before ultimately affecting human health and the environment. A better understanding of those processes is critical if the effects of existing or proposed new sources of air pollution are to be evaluated accurately. Researchers, therefore, will attempt to answer the following questions:

(1) What are the reaction products of pollution emissions? How do they vary with meteorological conditions?
(2) How far will the emissions and their products travel?
(3) How reliably can a pollutant found in ambient air be traced back to its source?

The best available answers will be incorporated into mathematical models that can be used to predict changes in air quality due to a source in question.

While dealing with these important source-receptor issues, research will also expand the body of knowledge of the health and environmental effects of the air pollutants. Some of the effects are well documented, so researchers will concentrate on filling gaps in the literature. Health effects researchers, for example, will attempt to determine the sensitivity of observed effects to changes in the size distribution of particulate pollutants. They will also determine whether there are interactive effects of pollutants by exposing subjects to combinations and mixtures of the substances.

There is concern that non-health-related effects of air pollutants (frequently termed "welfare" effects) are not well understood. Such effects include damage to plant life, crop yield reductions, impairment of visibility, and acid rain. Researchers will employ laboratory studies and field investigations to more accurately identify and quantify those effects.

Mobile sources of air pollution present a special set of problems requiring new research. Changes in engine design and vehicular fuel use will require tests that can determine whether different engine systems, fuels, and fuel additives pose unreasonable risks to health. Researchers will need to determine the ways in which specific engineering and fuel modifications affect biologic activity. Short-term tests for carcinogenicity, mutagenicity, and teratogenicity will be developed to effectively establish such relationships. Methods to characterize complex emissions from mobile sources will also be developed.

NONIONIZING RADIATION

Every day the U.S. population is exposed to radio frequency radiation from medical, industrial, and consumer product sources: radios, televisions, traffic radar, microwave ovens, electric power transmission lines, and satellite communications systems. As the number and power of existing nonionizing radiation (NIR) sources increase and as new applications of radiation are discovered, the public can expect its level of exposure to continue to rise.

Exposure to NIR, however, may or may not have human health effects. Effects have been documented for high-power NIR exposures, but the health effects at lower levels common in most American urban areas remain unclear. Because those health effects are not clearly known, research on nonionizing radiation is focused ultimately on determining them.

Researchers will develop techniques to increase knowledge of the health effects of chronic, low-level exposures; build a data base about the human consequences of NIR exposures; promote understanding of the health effects of broadcast frequencies; and establish a population exposure standard for NIR. Two specific problems that are likely to merit further study are the health effects of NIR emitted from direct broadcast satellites (DBS) and from electric power transmission lines.

PESTICIDES

Pesticides research has the dual objective of providing mechanisms for controlling pests harmful to the agricultural enterprise and providing a scientific basis both for understanding the risks that may be involved in their use and for considering appropriate regulations. The program is focused mainly on developing knowledge, data, and techniques to assess potential health and environmental risks from pesticides; quality assurance and technical assistance help ensure appropriate applications of the research results.

To evaluate the potential human health and environmental hazards from a pesticide, regulators must identify and characterize the populations at risk, assess the severity of their exposures, and determine the actual or potential adverse effects on health and ecosystems. Since determination of the adverse effects of pesticides is the most advanced of these factors, current research emphasizes exposure assessment, for which data are sparse and for which measurement and predictive techniques are relatively undeveloped.

Several direct methods for estimating human exposure to pesticides have been developed and validated; future research will be concentrated on refining indirect methods. Those people exposed occupationally will command a priority in the effort to assess human risk; exposures of urban residents to pesticides used for the home and garden will also be studied.

To reduce the complexity and costs of the human risk assessments, researchers will explore the possibility of extrapolating human exposure risks from one pesticide compound or pesticide use to other, similar compounds or uses. Also to be explored will be the use of surrogate compounds in lieu of separate studies for each individual pesticide. If those efforts prove successful, much expensive and time-consuming exposure testing by the government and by manufacturers may be eliminated. Research will also yield estimates of expected concentrations of pesticides in the environment and in organisms, and assessments of the significance of their presence and effect on environmental quality and human health.

Another focus of pesticides research is on integrated pest management (IPM) strategies that minimize the introduction of pesticides into the urban environment, reduce general pesticide exposure in urban settings, and moderate the current dependence on chemicals to control urban pests.

Future pesticides research needs include investigation into the effects of the inert ingredients in pesticides, a deeper understanding of how ecosystems function when exposed to pesticides, studies of biorational pesticides, and development of improved application methods and integrated pest management technologies. Representative species in the natural environment are also needed as "early warning systems" that signal a pesticide's potential for endangering human health.

WATER QUALITY

The fundamental objective of water quality research is to provide assessment methods and information that will help Federal, State, and local governments make water pollution control decisions that are scientifically defensible, cost-effective, energy efficient, minimally disruptive to ecosystems, and that make effective use of water resources. Research to support this objective will be concentrated on developing technical data for future water quality standards, water-quality-based effluent limitations, water quality management strategies involving point and nonpoint source control tradeoffs, ocean discharges and dumping, restoration of publicly owned lakes, hydrologic modifications in wetlands and other aquatic systems, and national strategies for protecting water quality and assessing the progress of water pollution control efforts.

The first research phase will deal with major, high-priority current problems. The second phase will support development of national water quality strategies by providing data about the emerging problems most likely to affect those strategies.

Work in the near term will fill gaps in existing health and ecological data that were used to prepare proposed water quality criteria for a wide range of chemicals. The research will also provide technical assistance to those responsible for revising the regulations for ocean disposal of pollutants.

Major research efforts will also help meet some of the expected information needs in the development or revision of water quality regulations. Research will yield improved procedures for deriving water quality criteria and making wasteload allocations among dischargers. It will also provide methods to assess more accurately the environmental and cost effects of proposed pollutant discharge and disposal actions and of proposed remedial measures.

Problems of a longer term nature are associated with toxic pollutant management, nonpoint source control, lake restoration, dredge and fill operations, and protection of ground-water quality.

Pollutants that will receive the greatest amount of study will be toxic and hazardous chemicals. Other factors to receive significant attention will be sediment, nutrients, and salinity.

Discharges from wastewater treatment plants, amounting to nearly 26 billion gallons of treated wastewater added to the Nation's waterways and land surfaces each day, are an additional environmental concern. Urban runoff—the washings from our streets, roofs, and other surfaces during rainfall and snow-melt—contributes another 16 billion gallons of contaminated water each day.

To reduce the risks to health and the environment posed by these discharges, researchers will focus on the development of treatment processes, control of toxic materials, management of sludge, operation and design of treatment works, and use of land and aquaculture techniques.

Since chlorine can threaten aquatic life, researchers will investigate such alternatives to the use of chlorine for disinfection as ozone and ultraviolet light. To control toxic pollutants, researchers will identify the sources of these pollutants in municipal wastewater systems, investigate conventional and/or new treatment technologies, study methods for controlling discharges at the source, and provide cost and systems analyses of the various approaches.

In seeking improved ways to manage sludge, researchers will demonstrate methods to compact sludge using simple aerobic microbiological techniques and will develop a vertical tube reactor for wet chemical oxidation. Also, to minimize the impact of in-plant sidestreams on plant performance, researchers will identify current deficiencies in plant operations and will devise improved operational procedures to counteract them.

DRINKING WATER

Can all Americans be assured of safe drinking water? While this has traditionally been a concern of State and local governments, the Safe Drinking Water Act of 1974 directed the Federal Government to share in the responsibility through establishment of drinking water standards and protection of drinking water and ground-water supplies. Drinking water research enhances the scientific and technical foundations that underlie government efforts to set standards and to protect ground-water quality. Objectives of the research are to identify those harmful substances that occur in drinking water with sufficient frequency to warrant regulation, define the effects of those substances on human health, establish analytical procedures to monitor contaminants, identify treatment processes or new treatment technologies capable of minimizing contaminant formation for reducing concentration levels, and develop and validate equipment and technologies for sampling and monitoring ground-water quality. Priority is given to the problem of ground-water contamination by toxic substances.

For many areas of the country, the only ground-water data available are those generated when serious episodes of contamination occur. The general lack of baseline data precludes attempts to rank potential contamination sources, to evaluate their relative adverse impacts on human health, and, in many instances, to define feasible pollution prevention and control techniques. The research program is designed to provide needed baseline information.

Its success depends on the capability to estimate ground-water contaminants accurately. Thus, soil permeability tests, particularly for industrial wastes containing significant amounts of organic solvents, will be developed and standardized. An emphasis will be placed on determining the gross biological activity in saturated and unsaturated soils; once determined, the information could lead to data on the magnitude of industrial waste contaminants in ground water. Methods will be developed for improved and effective use of radioisotope tracers to investigate ground-water contamination.

To maintain ground-water quality, knowledge of the vulnerability of nearby aquifers to contamination is crucial. To help select future sites for underground waste storage and disposal facilities, methods of characterizing the earth's subsurface will be emphasized. Information on the impacts of specific sources of ground-water contamination, as well as on the economic benefits gained from not polluting, is also needed. To provide that information, the research will describe the transport and fate of pollutants, characterize subsurface environments, and then concentrate on specific pollution sources.

In addition, organic and inorganic contaminants in drinking water will be studied. Researchers will look at potential health effects ranging from waterborne infectious diseases to cancer and cardiovascular diseases. Water treatment technologies will be investigated to determine their effectiveness in combating diseases that may be caused or exacerbated by ground-water pollution.

CLIMATE

The National Climate Program, initiated in 1978 and involving coordinated efforts of NOAA, DOE, USDA, the National Aeronautics and Space Administration (NASA), and the National Science Foundation (NSF), has provided the framework to enhance the Nation's understanding of climate and climate fluctuations. The program was established recognizing that climate has a major influence on such matters of national concern as energy consumption, agricultural production, and water resources management.

The first 5-year plan was completed last year. The basic strategy of the program is to sponsor research to expand our knowledge of climate while simultaneously producing useful climate data based on existing information. To this end, a set of priority activities has been established, and lead agency roles have been assigned. The six highest priority activities (called principal thrusts) are shown by activity category in Table 1. Research is a significant portion of all the activity categories. For example, the study of the global carbon cycle is a key element of the carbon dioxide thrust.

Principal activities to take place over the next several years include:

(1) Assessment of the impact of climatic variability on the economy of the Nation;
(2) Observations to gain basic understanding of natural and man-induced climate variability;
(3) Observations to help define climatic states and to study climate processes;
(4) Data management to compile, organize, and disseminate an objective record of the climate;
(5) Analysis and prediction of climatic fluctuations; and
(6) Development of information services to provide timely, tailored climatic information for use in applications and research.

Table 1—Priority Activities of the National Climate Program

Activity Category	Principal Thrust	Lead Agency
Providing climate products	Generation and dissemination of climate information	NOAA
	Climate prediction	NOAA
Responding to impacts and policy implications of climate	Carbon dioxide, environment, and society	DOE
	Climate and world food production	USDA
Understanding climate	Solar and earth radiation	NASA
	Ocean heat transport and storage	NSF

8 Transportation*

HIGHLIGHTS

- Sharp increases in energy costs have increased the costs of personal mobility and have far outpaced productivity gains in the transportation infrastructure, especially the air traffic control, highway, and railroad systems. In addition, more efficiency in now congested terminal areas will be needed to expedite the movement of goods. Concentrated efforts in transportation energy conservation will be necessary to reduce U.S. dependence on foreign oil, since the transportation sector accounts for over half of the U.S. consumption of petroleum. Lightweight structural components and electrification of vehicles are important research areas.
- The world trade position of the United States is undergoing rapid changes in the face of stiffening foreign competition. Research on electric and hybrid vehicles and new technologies in engines and drivetrains will enable the auto industry to produce a new generation of cars to compete in the international markets. The aircraft industry will apply digital electronics and innovative fuel-saving technologies to improve aircraft efficiency. Attention to port loading problems and other bottlenecks is necessary for competitive maritime transportation. Computer-aided design and manufacturing (CAD/CAM) and robotics techniques are being incorporated into the production of transportation equipment.
- Efforts must be made to provide the highest practicable level of safety for people and property exposed to and carried by the Nation's transportation system. Advances in telecommunications for navigation and warning systems and automation for highway transportation, mass transportation, and air traffic control will contribute significantly to safety. Movement of hazardous materials will continue to receive close attention.
- Mass transportation faces many difficult challenges. Chief among them are fuel inefficient and aging vehicles. In this labor-intensive industry, operating costs are rising sharply and, seemingly, inexorably, and productivity is lagging. New approaches to vehicle and plant maintenance and to operations are needed to overcome the productivity problem.

INTRODUCTION

Transportation has subtantially shaped the growth and development of the United States. Waterways led our ancestors to new frontiers, and today our waterway industry continues to move goods efficiently over the vast network of inland and coastal waterways. Railroads, which fed the hearths of an industrial revolution, now have renewed significance in an era of heightened environmental and energy consciousness. Highways made us the most mobile population on Earth, profoundly altered our land use patterns, and established the importance of the automobile, truck, and bus to the Nation's mobility and economic activity. Mass transit provided the lifeline to city centers and now offers hope for their revitalization. Aviation extended its reach around the globe and helped design the interdependent world in which we now live. Space transportation is increasing that interdependency and enabling the conduct of activities on global scales not formerly attainable.

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*Participants in the task group developing this section included representatives of the Department of Transportation, the Department of Energy, and the National Aeronautics and Space Administration.

The U.S. transportation system provides the Nation with the mobility it needs for a strong and cohesive economy. The network is enormous. Americans own more than 100 million automobiles that travel over nearly 4 million miles of roads. The scheduled airlines will transport more than 300 million passengers this year. The U.S. rail system is the largest in the world with more than 300,000 miles of track. The American merchant marine fleet numbers more than 500 ships; there are over 100,000 documented vessels and an additional 14 million pleasure boats. The Nation's pipeline system carries more than 2 billion tons of cargo annually. Public transit vehicles carry nearly 6 billion revenue passengers yearly: 4.4 billion by bus and 1.5 billion by rail.

Today, the U.S. transportation system faces many new challenges. Our ability to deal with those challenges will contribute to the future health of the Nation's economy because the interrelated and tenacious problems of inflation, energy dependence, and stagnating productivity are closely linked to transportation efficiency and effectiveness. Those problems have led to changes in our values, priorities, and material wealth, and the U.S. transportation system has had to adjust to the changing circumstances. The future will require even greater adjustments. We need a healthy, productive, responsive transportation system if we are to sustain and enhance the Nation's competitive position in world markets. Energy conservation and development must become a critical element of that system. We must also be able to transport people and goods efficiently if we are to realize our goals of renewed industrial and economic revitalization. While making those changes we must also maintain and improve the enviable safety record of our transportation system.

The importance of technological progress to economic growth has been the subject of much study. Although the precise relationship between economic growth and technological innovation may be unclear, there is little disagreement that innovation is a necessary element in economic growth. That is true particularly in the transportation sector, where technological innovations present many opportunities for enhancing its productivity, safety, and competitive trade position. A revitalized private industry will provide a vastly improved capability to deal with the transportation problems of the 1980s and 1990s.

PRODUCTIVITY

In recent decades, productivity in the United States has made, at best, only moderate gains. At the core of the problem have been declines in the savings rate and in capital investment; excessive government regulations, spending, and taxes; and a general decline in investments in research and development. For the transportation sector, productivity improvement has been particularly difficult because the large increases in the price of petroleum products have tended to far outpace any productivity gains. That trend can be expected to continue unless remedies are found for increasing fuel prices, labor problems, excessive regulations, high taxes, and declining investments. Advances in traffic control, structures and materials, and other transportation innovations would ensure that the U.S. transportation systems are able to support the increasing demands that will be made on them in the coming decade.

TRANSPORTATION INFRASTRUCTURE

Much of our highway system, which is used for 90 percent of the population's travel and accounts for 80 percent, by value, of goods moved, is rapidly wearing out. If trends continue, a major portion of the Interstate pavement will have deteriorated by the end of the 1980s, and bridge maintenance will remain a major problem. The total highway repair bill over the next 10 years will be in the hundreds of billions of dollars. To help deal with that problem, Congress has adopted the pavement resurfacing, restoration, and rehabilitation program and the bridge replacement program. The large investments to be made in those programs make the use of optimum materials and designs imperative. Asphalt and portland cement are presently the only competitive paving materials, and they are both energy intensive and in short supply. Although progress has been made in finding cost-effective substitutes (for example, sulphlex), basic research questions must be resolved to make their commercial exploitation practicable. When that occurs, the use of substitute paving materials can reduce construction costs and conserve raw materials by utilizing waste products as basic inputs in their production.

Similarly, the main line trackage of Class I railroads in the United States will require constant maintenance and repair. Research is needed to improve the efficiency of the investments that the railroad industry will make in plants and equipment to handle the increasing tonnages of coal and other commodities.

Improvements in nondestructive testing, new materials and techniques for the fabrication and erection of bridges can substantially reduce rehabilitation and replacement costs for both highways and railroads. Furthermore, research to improve the detection of highway material and rail structural flaws will reduce maintenance and repair costs.

Although the current air traffic control system, including voice communication subsystems, is adequate to meet near-term demands, its capability will be provided at ever-increasing costs to users, and there is practically no potential for adding new functions or enhancements. Increasing demand on the limited capacity of the system may result in congestion, which raises fuel consumption and retards the productivity of multimillion dollar investments in jet aircraft. At the present time, research into new avionics developments shows considerable promise for making significant fuel savings in cruise and approach configurations. The resulting new technologies can be expected to lower maintenance costs, allow the introduction of innovative safety and fuel efficiency improvements, support the transition to automated decisionmaking in air traffic control, and otherwise enhance controller and aviation industry productivity.

At the present time, approximately one third of the U.S. bus mass transit fleet has over 12 years of service and should already have been replaced. The mass transit rail infrastructure, including vehicles, equipment, and facilities, desperately requires repair or replacement. Allowing the continued degradation of those systems will result in massive shifts of ridership to autos with consequent energy, environmental, development, and congestion impacts. New approaches to equipment and facility rehabilitation can increase life expectancies, lower life-cycle costs, and improve the quality of service rendered.

GOODS MOVEMENT

Revitalization of the Nation's industrial plant and a renewed competitive economic position for the United States in world markets will require improved efficiency throughout the transportation sector. The development of new energy resources, the export of coal, and increasing movements of other commodities will place great demands on the freight transportation system. Productivity gains in freight transportation can be multiplied since transportation improvements induce additional gains in the producing sectors of the economy. Improvements in freight transportation can result in economies that will make U.S. coal, grain, and, especially, manufactured goods more competitive in world markets.

Improvements are needed not only for the line-haul system but also in terminals. Efforts to expedite the flow of cargo through terminals using advances in sensors, controls, and other technologies to handle materials, identify containers automatically, and manage the relevant shipping information have been seriously lacking. Additionally, improvements in both the material and the structure of containers for transporting hazardous materials and general cargo can lead to the elimination of many of the problems that adversely affect the movement of goods through terminal areas. Efficiency improvements made possible by research can dramatically increase system capacity, minimize equipment car shortages, and allow capital to be used for other purposes.

ENERGY

During the first three quarters of 1980, U.S. domestic consumption of oil dropped significantly, and gasoline usage declined to its lowest level in a decade. Nevertheless, the U.S. oil import bill is still a staggering $10.6 million every hour. That dependence on foreign sources of oil seriously threatens the Nation's economy. It leaves the United States vulnerable to supply interruptions, it creates a balance of payments problem that destabilizes the dollar, and it threatens the economy (in jobs, production, and prices) as industry struggles to adjust to increasing oil prices.

Dependence on foreign sources of oil will continue to be a matter of great concern in this decade. Because transportation is almost completely dependent on petroleum-based energy and uses roughly 50 percent of the petroleum consumed in the United States, it must participate substantially in energy conservation programs and increase the efficiency with which it uses energy. Successful research and development present a major opportunity for reducing U.S. dependence on foreign sources for petroleum products.

During the years when oil prices were artificially low, the automotive industry had little incentive to pursue the goal of fuel efficiency, and the demand for transit was not high. Increasing fuel costs have changed the picture. However, 90 percent of all vehicle miles traveled in the United States are by auto. Current conservation efforts, therefore, need to be focused on the auto and on personal transportation. Research must be directed at encouraging the automotive industry toward innovative approaches and solutions that improve fuel efficiency. For example, the feasibility of fuel-saving developments in engines and drivetrains has been demonstrated in prototype vehicles, and the use of lightweight structural designs is being pursued as a fuel-saving device. This effort in automotive research is similar to efforts in aviation to assess the effects on energy efficiency of using lightweight composite materials in aircraft seats and structural components. The work already completed on composite materials in aircraft suggests that such materials may also have applications in the automotive industry.

The electrification of transportation vehicles, both intercity rail and urban highway, is an attractive, long-range possibility for reducing petroleum dependency. It would provide a means of improving transportation efficiency using energy that can be generated from any relatively abundant source. During the past decade, the imperative for reducing petroleum consumption has generated major research, development, and demonstration programs for alternative automotive propulsion systems, including electric and hybrid vehicles, and for synthetic fuels from coal, oil shale, and other unconventional sources. Similarly, the use of such alternative fuels as hydrogen for aircraft is being explored. There is a need for an intensified research effort focused on improved technology for electrification of railroads. Specifically, research is needed to bring about a reduction in the cost of catenary construction, signal system modifications, and electric locomotives, thereby making electrification more attractive to the railroad industry.

In urban transportation, another possibility for reducing petroleum demand is a highway-based electrification system to support nonrail vehicles (buses, trucks, and autos). Currently being explored is the transfer of power through magnetic flux with no physical contact between the roadway and the vehicle, thus obviating the need for overhead wire systems or live surface elements.

WORLD TRADE

In an increasingly interdependent international economy, U.S. transportation provides vital links among the world's nations. Since the end of World War II, international trade and travel have grown very rapidly, and the United States has become increasingly dependent upon the foreign markets and foreign resources that international transportation makes accessible. The U.S. position in the world economy, however, is rapidly changing as our traditionally strong industries struggle to maintain leadership in the face of growing competition from abroad. In transportation, the changing nature of world markets is particularly evident for the automobile industry, mass transit technologies, aircraft manufacturing, the maritime industry, and advanced production electronics.

AUTO INDUSTRY

In 1977, sales of full-sized passenger vehicles in this country held a solid 30 percent of the market. Today, that share has shrunk to 15 percent, while small car sales have grown to over 60 percent of the market, and nearly half of the small car sales are imports. To survive and to reassert its previous world market leadership, the American automotive industry must devote more resources to scientific and technological development. Some research in progress has shown promise for the automotive industry. Important advances have been made in electric and hybrid vehicles. In addition, prototype vehicles are being developed to demonstrate that current technology in improved engines and drivetrains can be integrated with structural improvements to provide greatly enhanced fuel economy. Such breakthroughs in both basic and applied automotive research will help the industry develop a new generation of cost-competitive, fuel-efficient, and environmentally sound automobiles that can compete in the international market in the coming decade.

MASS TRANSIT

U.S. transit vehicle manufacturers and their supplying component industries are also being affected by foreign competition. Many cities are purchasing articulated buses that are foreign made. The most popular small bus in many urban areas for transit routes with lower passenger volumes and for specialized transportation to elderly and handicapped persons is foreign made. Many transit operators, dissatisfied with the new generation of transit buses, are ordering buses manufactured to meet specifications of the last generation.

Currently, there are only two major full-sized bus manufacturers and one rail car manufacturer within the United States; the rail car manufacturer is foreign owned. The major problems confronting U.S. transit vehicle makers include a small market (limiting the incentive to invest in innovation), the tendency of suppliers and subsuppliers to produce for applications other than transit and to minimize modifications necessary to fit transit users, and the perceived instability of the transit market.

AIRCRAFT MANUFACTURING

Exports by aircraft manufacturers increased dramatically in the late 1960s through the mid-1970s. More recently, there has been another surge in the demand for U.S.-manufactured large transport aircraft as a result of the desire of major world airlines to reequip their fleets with more fuel-efficient planes. Nevertheless, the commercial success of the European consortium's A-300 Airbus poses serious competition for U.S. airplane manufacturers. In addition, while two thirds of all U.S. domestic air passengers board small planes designed for short- and medium-range trips, those small planes being operated by U.S. airlines are often of Canadian, French, and Brazilian manufacture. Maintenance of U.S. market dominance in airplane manufacturing is especially important in light of the industry's contribution to the U.S. trade balance. Recent penetration of domestic markets by foreign manufacturers has sent a clear message to the U.S. aircraft manufacturing industry.

Considerable Federal scientific and technological investment is being made in improving the fuel efficiency, productivity, and utility of both large and small transport aircraft. Already, advanced guidance, navigation, and flight control systems and displays have been developed and verified by flight tests so that the industry has sufficient confidence to incorporate digital electronics technology into the new generation of large transport aircraft. Similarly, innovations in aircraft propulsion technology and lightweight composite materials show great promise for significantly enhancing fuel efficiency. Continued innovations of those types are necessary, however, if the U.S. aerospace industry is to continue to predominate in competitive domestic and international markets.

MARITIME INDUSTRY

The vast preponderance of our foreign trade moves by ocean vessel and is expected to do so for the foreseeable future. For this reason, the cost and quality of maritime transportation are of vital concern to the U.S. economy. However, even though the United States maintains and promotes a flag merchant marine fleet, it carries only a small part of our foreign trade.

Recent technological developments in ocean shipping could change the international situation. The introduction and growth of unitized cargo systems have opened vast opportunities for more rapid, secure, and efficient movement of goods. The technology has promoted the development of new families of ocean-going vessels that, being capital rather than labor intensive, tend to reduce the competitive disadvantages of U.S. vessels. However, better methods for transferring cargo through terminals are needed desperately. Improvements in sensors, automatic container identification, and the handling of shipping information are required so that terminal areas do not remain bottlenecks. Likewise, technological improvements in containerized vessels will provide more flexibility in supplying the changing commercial markets while also enhancing the ships' utility for national defense.

A major maritime innovation has been the supertanker. That quantum jump in technology has raised special problems in navigation and traffic separation, pollution, and the adequacy of port facilities. The potential economies of scale that supertankers provide have not been fully tapped because technological hurdles in ports, loading facilities, and other areas have yet to be satisfactorily addressed.

ADVANCED TRANSPORTATION PRODUCTION ELECTRONICS

A supporting technological development that holds promise for aiding the U.S. transportation manufacturing industry is computer-aided design and manufacturing (CAD/CAM). Those techniques are being rapidly introduced into the Nation's industrial plants. Innovations include product design and drafting with the aid of specialized software, numerically controlled machine tools, and a whole range of computer-aided manufacturing processes (for example, reliability engineering).

Although the potential benefits of CAD/CAM are substantial, the adoption of the new disciplines in the manufacturing of transportation equipment has been lagging. One constraint has been that successful approaches to many of the "pieces" of computer control systems, for example, three-dimensional modeling, have not been developed. However, a properly directed research program can readily breach such technical barriers. University research, conducted in cooperation with the transportation equipment industry, can assist in bolstering CAD/CAM technology in the transportation industry in several ways. First, such university programs will help to train specialists. Second, the programs will develop improved hardware and software for design and manufacturing tasks. Together, those changes will ultimately make available the personnel and technical bases that will accelerate the rate of adoption of CAD/CAM techniques. Then industry can expect increased worker productivity, improved product quality, shortened lead times in bringing out competitive new products, and flexibility in adapting models, for instance, new cars, to customer preferences.

Robotics is another technology of crucial importance to the modernization and increased productivity of the U.S. transportation manufacturing industry. Once again, it is an area in which the United States has lagged far behind its foreign competitors. The Japanese, presently the world's leaders in robot technology, have demonstrated the use of robots for such industrial processes as cutting and grinding, pressing, plastic molding, welding, die casting, heat treatment, and assembly. The largest area of demand for robots in Japan has been the automobile industry, accounting for 35 percent of total robot use. The United States has the capability to be the world leader in innovation, use, and export of robotics; however, the research needed to develop and realize fully the benefits of the technology must be programmed and completed.

SAFETY

The size and complexity of the U.S. transportation network inevitably involve accidents that result in deaths and serious injury. While a completely accident-free transportation system is not possible, we must seek to provide the highest practicable level of safety for people and property exposed to and carried by the Nation's transportation systems as we seek to deal with transport-related economic, energy, and environmental issues.

Although motor vehicle fatalities account for most transportation-related deaths, substantial losses are also due to aviation, railroad, and maritime accidents. Safety efforts must be directed toward protecting occupants, improving vehicle right-of-ways, increasing operator skills, and safeguarding the transport of hazardous materials.

TELECOMMUNICATIONS

Advances in telecommunications bode well for improving the safety and efficiency of transportation. The innovative use of improved capabilities in radionavigation, radiolocation, and radiocommunication systems can provide services that are economical and environmentally sound and that also meet safety needs. The requirements for improved and coordinated navigation systems are becoming more stringent as the numbers of vehicles in the airspace and on the waterways increase. On highways and railroads, there is an urgent need for systems to provide coverage in built-up areas and for systems to serve less densely populated areas.

Rapid advancements in electronic communications and computer microprocessor technology have combined to produce small and reliable electronic hardware at low cost. The availability of that hardware has improved the feasibility of developing systems to forewarn drivers of highway hazards concealed by intervening curves, fog, or other conditions. Similarly, technological innovations in weather radar will provide dramatic improvements in the detection and warning of severe conditions and provide improved general weather information for air and surface vessel traffic. Also, advances in beacon technology will enhance the safety of air travel by reducing the potential for mid-air collision. Using state-of-the-art telecommunication and related devices, research is being conducted to provide more efficient consumer inquiry information to transit users, to improve transit system and vehicle management, and to increase passenger safety and security. Those improvements are vital to maintaining existing transit systems and to improving their productivity and efficiency.

SYSTEM IMPROVEMENTS

Automation in highway transportation, mass transportation, and air traffic control holds the possibility for major improvements in system safety as well as in productivity, energy conservation, and other areas. However, people will remain active participants. Research into automated traffic control must place considerable emphasis on promoting a man-machine interface that lets the person understand what the machine is doing and why it is doing it, and provides for intervention as necessary. Techniques that enable a computer to analyze and evaluate its performance and thereby improve its future performance (in other words, "learn from experience") will serve to increase human confidence in highly automated control systems. Highway automation not only requires technical hardware development but may involve major institutional changes. Likewise, transit would require hardware and software development before significant improvements in service can be achieved. Finally, introduction of higher levels of automation to air traffic control functions will require replacing hardware and software now located at 23 domestic and offshore control centers. Numerous technical hurdles will have to be overcome before a replacement system can be integrated into the existing control system in a way that is not disruptive to controllers, pilots, and other users while maintaining system reliability approaching 100 percent. Advanced electrification technology, an attractive possibility for bus, truck, and auto system improvements, has potential for enhancing transportation safety.

HAZARDOUS MATERIALS

The safety record for the transportation of hazardous materials is remarkable in view of the large volume of such shipments. Over 250,000 hazardous materials shipments per day are estimated to move through the U.S. transportation network, and the shipment of hazardous materials is expected to grow faster than that of other commodities over the next 10 to 15 years.

Accidents leading to casualties primarily involve only a few of the nearly 2,000 regulated commodities. Continuing research is needed to develop and use technological applications and advances to improve the safety of transporting hazardous materials. Because of the possibility of a catastrophic occurrence, local communities have begun to generate State and local laws designed to protect themselves. Some of those laws may imperil their neighbors and impede the flow of goods. Research holds the key for developing innovations to prevent catastrophes and the technical bases for sound operational practices and procedures. For example, extensive research into new technology to transport liquefied natural gas, a super-cold, highly explosive material, is needed. There is also a need for innovations in the identification of hazardous materials in transportation mishaps, emergency response mechanisms, and information dissemination.

9 Agriculture*

HIGHLIGHTS

- The need to increase agricultural production despite the scarcity of both new land and new water resources is a challenge for science and technology. Solutions exist in better management of existing natural resources while also increasing crop and animal productivity through biological research and management of their environments, including innovative approaches to disease and pest management.
- Meeting national needs for ensured adequate food supplies and improved health through nutrition involves efforts to define nutritional needs; monitor eating habits; determine the nutritional value of foods; and assess the effects of food assistance, nutrition education, and other government programs and policies.
- Significant issues in food marketing and postharvest technology are addressed by research and technology transfer to improve food safety, reduce product losses, and lower production costs.
- The structure of agriculture, or the way the industry is organized to carry out its functions, is a significant factor in its ability to meet national needs. Challenges exist for science and technology to focus on (1) the structure of farming, ranching, and the food industries; (2) the impacts of the adoption of new agricultural technologies; and (3) agricultural production of nonfoods, including natural fibers from renewable resources, plant-derived industrial hydrocarbons, and energy.
- Employment and income in rural communities lag behind those of urban areas. Opportunities exist to assist rural areas with research and development on improved waste management, transportation, communication technologies, and appropriately scaled technologies for rurally located plants and services.

INTRODUCTION

National needs in food and agriculture include ensured sufficient agricultural production to meet growing domestic and export demands, adequate returns to farmers, dampened fluctuations in food prices, improved health through better nutrition and food safety, better management of the natural resource base, and improved efficiency and reliability in domestic and export marketing systems. It is the mission of food and agricultural science, technology, and education to ensure that those needs will be met with increasing effectiveness even in the face of ever-increasing challenges.

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* Participants in the task group developing this section included representatives of the Department of Agriculture, the Department of State, and the National Aeronautics and Space Administration.

There has been growing concern about the supply of graduates of higher education qualified for employment in food- and agriculture-related positions. Under the assumptions and criteria of a recent study,[1] an imbalance in the supply of, and demand for, graduates of higher education in the food and agricultural sciences is shown. It appears that estimated supplies of graduates with advanced degrees will not be able to satisfy the envisioned employment demands in a number of fields.

Issues deriving from the needs mentioned above are being addressed by science and education programs in the Department of Agriculture (USDA) and by cooperative, coordinated, or independent efforts in other agencies, including the Departments of Commerce, State, Health and Human Services, and Energy; the National Aeronautics and Space Administration (NASA); the Environmental Protection Agency (EPA); and the land-grant and other universities.

Opportunities and problems within five broad topic groups are described in the following paragraphs. The first topic group describes agricultural resources and productivity as they relate to the food and fiber supply. The second group describes the area of human nutrition. A third set relates to marketing and postharvest technology for food and agricultural products. A fourth topic is the structure of agriculture and agricultural policy. Finally, issues in rural and community development are addressed. The order of presentation is not an indication of priority, since each organization interested in agriculture would place a different emphasis on what is most important.

AGRICULTURAL PRODUCTION

Continued concern for increasing American agricultural capacity reflects projected increases in world population, the growing role of agricultural output in world trade, and opportunities for using agricultural products and byproducts as substitutes for nonrenewable resources or to augment supplies of otherwise scarce commodities. Shortly after the beginning of the century, most of the better agricultural land had already been brought into production. Between 1944 and 1974, irrigated land acreage doubled. As the 1980s unfold, both new land and new water for agricultural development are becoming increasingly scarce. That means increases in agricultural capacity must come from more careful management of natural resources and from productivity improvement.

Providing enough agricultural production is a complex issue. It is treated here as a hierarchical structure of subissues, including groupings in the major areas of natural resources and the environment, crop productivity, animal productivity, and pest management.

NATURAL RESOURCES AND THE ENVIRONMENT

Consideration of natural resources and the environment in relation to agricultural production requires a multidisciplinary approach to research and to technology transfer. Problems exist because of shifts in priorities, more intensive uses of resources, and the need for humans to share the environment for differing purposes. Thus the opportunities for and the constraints on contributions to resolution of natural resource issues by science and technology may, themselves, be judged in human value systems as part of the issues.

Environmental Concerns

Environmental regulations and low economic returns place constraints on the American farmer in his effort to produce food and fiber. Farmers will need to institute some practices that are not cost-effective in the short term if they are to comply with environmental regulations. This implies that increased emphasis should be placed on developing procedures to assess the effects of soil and crop management practices on runoff, erosion, and water quality and on developing new management practices to ensure a continuing high level of production while maintaining or improving the quality of the environment.

The costs of complying with environmental regulations, given current technology, may vary substantially among different geoclimatic farming regions and among different enterprises. For example, research results indicate that the cost of meeting environmental requirements while disposing of wastes from some confined livestock operations are higher for smaller enterprises and that costs are affected by temperature, water balance, soil characteristics, and topography. The cost differences may encourage development of more large-scale enterprises, with subsequent shifts in the location of production and the necessity for adjustments in resources and produce markets. However, the cost of transportation may prevent regional shifts in many commodities. The extent of such impacts will depend upon the development and use of new technologies and systems. Where environmental objectives are competitive with production objectives, impact evaluations of prospective technologies and compliance policies would assist in the selection of alternatives.

Land Issues

America's land resource base will be called upon to produce an ever-increasing quantity of food, fiber, and timber. At the same time, the increasing population means that additional land is needed for nonagricultural purposes. Almost 3 million acres of cropland (much of it prime farmland) are diverted from agriculture to other uses each year. As the better land is removed from the agricultural cropland base, farmers shift to less suitable land, where, given the same technology, yields are lower, costs are higher, and environmental pollution through erosion increases. Basic research on the chemical and physical properties of soils provides opportunities to develop systems of farming practices that utilize less than prime lands more efficiently in the production of food and fiber without significantly contributing to increased degradation of soil and water resources.

Economic and legal analyses of Federal, State, and local policies and programs on rural land use are needed, particularly as those policies and programs affect the allocation of land for agricultural and other uses. Identification of such institutional factors as tax structures, inheritance laws, zoning provisions, and other variables affecting land use is needed to aid research and economic intelligence with respect to land use planning and policy, consequent distributional impacts, and economic effects on U.S. agriculture.

It has been estimated that 2 billion tons of agricultural soil are eroded annually. Erosion of that magnitude dampens prospects of continued long-term productivity increases. Research is needed to determine the relationships between soil erosion and agricultural productivity to assist in the development and selection of appropriate conservation tillage systems and other technologies for soil conservation.

Water Issues

Industrial, household, and agricultural water requirements are increasing. As a result, ground-water withdrawal in many parts of the world vastly exceeds the rate at which it can be replenished. In the United States, over one fourth of total farm receipts come from the 12 percent of the cropland that is irrigated, and the use of irrigation is increasing in all areas of the United States where water resources are available at a reasonable cost. About 40 percent of the irrigation water is ground water. Projected domestic water use by the increasing population and for energy production indicates that the Nation is fast approaching the point where the availability of fresh water may be *the* limiting factor in food and fiber production.

Science and technology offer opportunities to develop irrigation management systems for utilizing and distributing water more efficiently. They include drip irrigation, irrigation scheduling, and recycling of wastewater. Scientific and technological capabilities can also be used to shape alternative farming systems; for example, research can lead to the development of plants that require less water or are more adapted to saline water. A third way that science and technology can assist in conserving the supply and maintaining the high quality of water is by development of strategies for the replenishment of ground-water aquifers.

There is also a need for technical information on the fate and pathways of chemicals in the soil and associated water under irrigated conditions. With rapidly changing costs for plant nutrients and irrigation water application, the existing technical data are out of date and no longer adequate for providing the best recommendations for sound irrigation/cropping systems. Water quality plans are also difficult to formulate due to rapidly increasing energy and water costs. Basically, research is needed to compile proven technical and economic information on chemicals in the soils and associated ground water and to improve knowledge of the nitrogen cycle and the related effects of organic farming and waste recycling.

As the Nation moves to greater dependence on coal as an energy source, the acidity of precipitation is expected to increase, potentially inhibiting gains in agricultural productivity by introducing yet another stress on crop plants and natural ecosystems.

Weather and Climate

While cyclical changes in precipitation patterns have led to drought conditions in most areas of the world, excessive precipitation also delays planting and creates poor growing and harvesting conditions. There are two ways to help those managing the food system to adapt to changing weather and climate patterns. One is through improved forecasting; the other is by better understanding of functional responses of water supplies, crops, and animals to adverse weather.

CROP PRODUCTIVITY

The rate of increase in the yields of major U.S. crops in the last decade has been declining. Several studies have projected that the world population will grow to 7 or 8 billion in the next several decades. That implies expanding world demand for U.S.-produced crops. During the last decade, the United States has been relying increasingly on crop exports for relief from foreign trade and exchange imbalances due to a restructured world energy situation.

Opportunities for scientific and technological contributions to increasing crop productivity may be classified in two broad categories: the biology of the plant and the control and management of the plant microenvironment.

The Biology of the Plant

Traditional approaches to improving plant physiology through breeding have been important in increasing the crop yields in the United States. They are the approaches to be relied on as the principal current efforts to improve and maintain crop yields and to upgrade nutritional quality. Some of the newer technologies should be viewed as supplementary to basic approaches, experimented with, and developed as scientific opportunities for the long term.

A thorough understanding of the systematic relationships involving combinations of organisms permits maximum use of genetic variability in striving to reach specific objectives in crop protection and crop improvement. Such new approaches and technologies as comparative phytochemistry, computer-assisted analyses of plant population dynamics, correlation data in systematics, and the increased emphasis on cytogenetics, breeding systems, and biosystematics, along with the well-known traditional approaches, provide a basis for potential success. Reduction of losses caused by environmental stresses associated with temperature, moisture, air pollution, soil mineral content, salinity, and acidity is a time proven objective of plant breeding. Crops that can be grown economically on less productive land must be developed. The optimization of genetic-environmental interaction must be accomplished through both breeding and cultural practices. Traditionally, environmental modification has been emphasized independently of breeding, but there is an opportunity for breeding to contribute much more. Major refinements can come through genetic tailoring of plant species to meet environmental stresses and pest problems. That requires the broadest possible array of genetic diversity in germplasm collections of crop plants.

A concerted multidisciplinary effort could contribute to better definition of each of the stages that help to determine a plant's net photosynthetic efficiency and to define interrelationships among the several functional stages in the total physiological system of the plant. Improved knowledge is a prerequisite to the development through genetic and plant breeding research of commercial plant varieties having higher levels of net photosynthetic efficiency and higher yields in a given microenvironment.

Genetic modification of cereal grain plants to utilize nitrogen-fixing bacteria would sharply reduce energy requirements and costs of production; it would also reduce the threat of environmental pollution from use of nitrogen fertilizers. A concentrated effort to identify and define areas and methodologies for using recombinant DNA technologies for advances in the crop sciences and technologies would address those ends.

A constraint that is threatening the potential of classical plant breeding methods for achieving improved plant productivity is that the sources of genetic diversity for some crop plants and their wild relatives are rapidly diminishing, and resources are not currently available to adequately evaluate crop germplasms. Constraints on developing plants for stressful environments include the complexity of incorporating stress resistance into the array of plant breeding objectives, the insufficient evaluation of germplasm collections to identify needed genetic traits, and the growing need for the formation of interdisciplinary teams that include plant breeders, physiologists, and soil scientists.

Management of the Plant Microenvironment

The demands on the biosphere of expanding population are accompanied by continuous pressures to establish and manage ecosystems that optimize food production while providing other benefits. Major opportunities for contributions by science and technology lie in the continuing development and assessment of technological and management alternatives including the establishment of different crop plant densities, plant associations, plant selection, cropping patterns and crop production, pest management systems, and fertilizer systems. Also needed are efforts to meld independently developed information and subsystems addressed to agronomic practices, integrated pest management, and weather and climate into more comprehensive integrated crop production systems. The ways that such management and technological alternatives affect ecosystem management for broad economic and social objectives should be assessed. Additional attention to increased rangeland productivity potential as a source of feed for ruminants, for environmental quality improvement, and for improved wildlife habitat seems warranted.

ANIMAL PRODUCTIVITY

Sales of animals and animal products from farms represent at least one half of the total value of farm products. Animals and animal products supply many of the essential nutrients consumed by man. Ruminant animals convert plant materials that would not otherwise enter the food chain. Research and education on animal protection and production are essential to the continuation of the plentiful and economical supply of animal foods that the American consumer enjoys.

The Biology of Animals

The breeding herd in a meat animal industry is portrayed as a capital investment for the production of meat by its provision of progeny. The longer the gestation and sexual maturity periods, the higher the overhead costs. There are opportunities through science and technology to improve the reproductive performance of beef and dairy cattle, sheep, and swine.

Increased efficiency in animal production depends upon improving genetic capabilities for specific purposes. For example, continued changes over time have been reflected in greatly reduced fat in pork carcasses, increased milk yield per cow, and increased rate and efficiency of weight gain in broilers and swine. Major opportunities exist in such areas as (1) breeding and selection to improve genetic capacity for production, (2) reducing current losses and overhead costs due to reproductive problems, (3) increasing the efficiency of feed utilization and determining the relationship between nutritional status and disease susceptibility, (4) developing methods for increasing the use of feedstuffs not directly utilizable as food for people, and (5) modifying the ratios of fat to protein in animal products by genetic, physiological, and nutritional approaches.

Aquaculture

Aquaculture, the controlled cultivation and harvest of aquatic animals and plants, offers numerous opportunities for science and technology to contribute to continued growth in the food supply. Research and transfer of information can help to improve production, processing, and marketing practices and to reduce environmental pollution resulting from aquaculture production and/or processing.

Management of Animal Environments

Diseases and infections are of major concern in the management and production of food-producing animals. Their control requires the same kinds of research and technology as does control of similar diseases and parasites in humans.

The environment in which livestock are kept affects their production and reproduction efficiency. Research on environmental management systems provides continuing opportunities for finding ways to adjust to both technological developments and changes in prices and costs.

Current concerns likely to persist through the next 5-year period include consumer, nutritional, and environmental issues involving livestock and livestock products. Those issues increase the challenges to animal scientists for prioritizing and allocating research resources. Constraints on animal science and technology include the enormous costs of developing and testing new chemicals or drugs, the appearance of pests resistant to drugs and chemicals, the absence of basic research upon which to build new technologies, the rejection by society of some methods of predator control, and the redistribution of research resources to address additional problem areas.

PEST MANAGEMENT SYSTEMS

Since pests play such an important role in agricultural productivity, they are treated separately here rather than in the context of crop and animal productivity. To increase productivity through pest management systems, major emphasis is accorded to selective chemicals, biological controls, attractants, and breeds or varieties of animals and crops that are either resistant or more tolerant to the attacks of various insects and diseases. Of prime importance in developing improved control technology is research on insect physiology, genetics, and behavior. Pest management systems can be used to prevent and/or control many diseases, weeds, and parasites that currently cause large losses.

Evidence of adverse effects of chemical pesticides has resulted in increasingly stringent constraints on their use. Given the magnitude of pest losses, this development has created the potential for a large social return from development and use of environmentally safe and effective pest management strategies for a wide variety of crops and animals.

The movement of people and goods throughout the world increases the risk of introducing new pests. Management options for reducing that risk include improving quarantine procedures, improving methods for early detection of foreign pests, and expanding science and technology programs in other countries aimed at establishing integrated pest management procedures to lessen the introduction of pests into the United States. The concept of integrated pest management (IPM) is the selection, integration, and implementation of pest control tactics in a systems approach based on anticipated economic, ecological, and sociological consequences.

New pest control approaches derived from the study of plants and animals themselves will be increasingly drawn upon to reduce dependency on chemicals that have potentially adverse effects on the environment. Approaches that already exist include the use of plant, insect, and nematode pathogens; pest-resistant plants; insect attractants, pheromones, and hormones; and cultural and mechanical methods for disease, insect, nematode, and weed control. These are combined with such biological controls as parasites and alternative chemicals.

Improved impact-evaluation tools could contribute to more accurate determinations of cost-effectiveness and economic impacts of alternative pest control strategies, including IPM practices. There are numerous opportunities for research on the environmental, economic, and social impacts on agriculture of alternative Federal environmental quality standards, policies, and programs, including the impacts on farm production costs, income, and consumer prices.

HUMAN NUTRITION

As the Nation has become increasingly interested in promoting health and preventing disease, nutrition has received heightened attention. Various groups have examined human nutrition research activities at the Federal level, and their numerous reports have recommended research priorities.

In March 1979, USDA published its own priorities for the upcoming decade. In *Food and Nutrition for the 1980s: Moving Ahead,* the Department defined six major areas of research that illustrate the integrated direction research must take if it is to provide answers for immediate application in critical national policy areas.

NUTRITIONAL NEEDS

Information on the nutritional needs of people of all ages is important. Specific high-priority areas can be identified for every age group ranging from the prenatal to the elderly. There is a particular need to define the relationship between diet and the chronic diseases that are the major health problems of Americans. The role of nutrition in optimal intellectual and physical development, in the outcome of pregnancy, and in the aging process, which involves an increasing proportion of the American population, is an area for increased research efforts.

EATING HABITS

American supermarkets today offer consumers the opportunity to choose from among some 11,000 items. New products are introduced almost daily. Others disappear from the shelves. Our food supply is a kaleidoscope of constantly changing packages, products, formulas, and conveniences. Thus, individual eating patterns are changing faster than we can presently monitor them.

Present survey techniques do not adequately measure what people eat. Efforts to formulate national nutritional policies or to design intervention programs, educational programs, or possible regulatory actions need to be based on knowledge of the factors affecting consumer food choices. Therefore, it is important to revise the methods we use to find out what individuals eat and find new ways to measure economic and nutritional impact.

FOOD FLOWS AND NUTRITIONAL VALUE

Information is needed about the nutritional composition of food and on the amounts of certain important nutrients and their availability in various foods and diets. Much current data may be obsolete because of differences in plant and livestock varieties and bloodlines, food production and processing methods, and food storage and delivery systems. New information is required to design programs that will encourage optimal food choices.

Research on nutrient availability is needed to:

(1) Identify and investigate the factors (for instance, the chemical form of the nutrients) that affect the ability of people to utilize nutrients in specific foods and the relationship of nutrients to other food constituents that inhibit or promote nutrient utilization; and
(2) Determine the social and economic feasibility—and nutrient possibilities—of new or improved food processes.

IMPACTS OF ASSISTANCE AND NUTRITION EDUCATION PROGRAMS

Research estimating the impacts or the likely impacts of nutrition assistance and education programs assists the managers and decisionmakers responsible for government food assistance programs, regulation of food fortification and enrichment activities, and nutrition education programs. Improved methodologies for measuring program effectiveness will more distinctly identify groups most vulnerable to poor food habits, behavior changes, and social and economic benefits resulting from the intervention. The results of analysis, evaluation, and testing of nutrition information and education programs provide opportunities to improve program effectiveness. One such opportunity lies in the interpretation of dietary behavior, knowledge, and attitudes that interfere with health-promoting food consumption practices. Another is in identifying ways to reach, appeal to, and motivate the general public and groups with special needs to adopt or sustain good dietary practices.

IMPACTS OF GOVERNMENTAL POLICIES AND REGULATIONS

In addition to programs intended to directly influence dietary practices, numerous other policies and programs also affect our food habits and nutritional health even though that may not be their sole or major purpose. Continuing elevation of our nutritional health consciousness leads us to the realization that nutritional effects have not often been included when such policies, programs, and regulations are evaluated.

For example, little is known of the nutritional effects of government activities in establishing and enforcing food grades and standards; packaging, labeling, and advertising requirements; and other measures to regulate marketing practices. Similarly, little is known of the extent to which nutritional behavior is "explained" by government food production and export strategies, agricultural research and extension programs, and rural credit services. Beyond programs directly related to foods, the issue of our nutritional health is rendered even more complex by the lack of information on the direct and indirect nutritional effects of transfer payments, income taxes, manpower policies, health programs, environmental policies, and other general government interventions.

DIETARY NEEDS IN OTHER COUNTRIES

Billions of people suffer from malnutrition and hunger worldwide. Research designs could take into account a range of circumstances that may differ widely from those in the United States. Such circumstances could include:

- The dietary needs and food practices of other countries;
- Differing political and cultural systems;
- The impact of land reform in some areas;
- The effects of low-protein, low-calorie interactions, and other nutritional deficiencies on the growth and development of children;

- High incidences of diseases and stress conditions in many countries;
- Waste, inefficiencies, and costs in food production and marketing;
- The lack of worldwide data systems for food supplies; and
- The lack of early warning of impending food shortages.

MARKETING AND POSTHARVEST TECHNOLOGY

Marketing and processing make up two thirds of the consumer's food costs and a much higher proportion of fiber product costs. As domestic and world populations expand, those costs will be of increasing concern, as will questions of food safety, marketing efficiency, processing, and the reliability of the domestic and export marketing systems.

FOOD SAFETY

Food and feed contamination can result from naturally occurring toxicants and microbial damage as well as from chemical residues, pathogenic microbes, and additives. The aims of continuing research are to improve our ability to identify chemical and biological contaminants; develop rapid methods for detection; determine causes and potentials for occurrence; and devise means for prevention, removal, and safe disposal of contaminated products and measure the economic consequences of those means.

Public issues of food safety and quality include human value judgments as well as economic, chemical, and biological components. Improved anticipation and analysis of the many issues would help to reduce controversy and provide a basis for the formulation of improved food quality controls.

PRODUCT LOSS AND COST OF PRODUCTION

Postharvest food losses for the United States have been estimated at $31 billion dollars, and losses of over half the food produced have been reported in less developed countries. As the domestic and world populations expand, it will be increasingly important to reduce food and fiber losses. There are opportunities to reduce those losses through improved commodity protection; preservation of food by environmentally acceptable methods to prevent contamination by insects, microorganisms, and toxic materials; and prevention of physical loss by damage. Potential improvements in technology include controlled atmospheres and temperatures, hormone bioregulators, low-dose atomic radiation, and pH control.

Processing, materials handling, and transport are major cost components in domestic food marketing. Science and technology capabilities can address methods that are more energy efficient, reduce product handling, and improve product protection without adding packaging materials or transportation costs. Such technologies as ambient cooling of produce and direct marketing of fresh rather than processed foods should be reexamined in light of increased energy concerns. Central to the development of new technologies to reduce food losses is the need for basic research on mechanisms of stress and damage in the harvested product.

STRUCTURE OF AGRICULTURE AND POLICY ISSUES

The structure of agriculture is defined here as the way the industry is organized to carry out its functions and how it performs to meet national needs. In this context, the national concerns are to ensure sufficient agricultural production to meet domestic needs and export demands, provide an adequate return to farmers consistent with the costs of production, and minimize fluctuations in food prices.

Four categories of structural and policy issues that either were not addressed or were discussed in a different context in preceding paragraphs are discussed below. They are: the structure of the agricultural industries, impacts of the adoption of new agricultural technologies, world food and fiber forecasting, and potentials for increased nonfood utilization of agricultural capacity.

STRUCTURE OF THE AGRICULTURAL INDUSTRIES

Farming and Ranching

Trends toward fewer and larger farms, increased capital needs in agriculture, and renewed economic pressures on traditional family farm organizations are among the vital issues confronting U.S. agriculture. They present challenges and opportunities for the social, physical, and biological sciences to contribute knowledge about the impacts on the structure of agriculture and the well-being of farmers deriving from government programs and regulations; marketing changes; economic instability; new technology; changing organizational arrangements; escalating land prices; National, State, and local tax policies; and increasing capital requirements for farming. The prospects in the next decade are for even larger and fewer farms, more concentration of wealth, more vertical integration, more contracting linkages with agribusiness, and reduced decisionmaking autonomy and independence of farmers. Analysis of those issues, including such alternative systems as organic farming, will provide policymakers with a better understanding of the impacts of the economic and technological developments affecting the structure and organization of agriculture and alternative program and policy options.

The Food Industry

The food industry operates under a myriad of Federal, State, and local regulations. It has also become highly concentrated and is characterized now by many of the competitive practices of the nonfood industry—product differentiating and advertising, nonprice competition, and high product turnover rates. The high costs associated with food marketing and related government regulations are of concern to both policy officials and the public. There are important opportunities for research to contribute to (1) determination of the effects of government regulations, technology, and the structure of competitive behavior in food marketing and distribution on the costs and other elements of performance related to manufacturing and distributing food and fiber; and (2) identification of new alternative marketing structures and methods that would enhance small and part-time farmer access to markets and increase opportunities for consumers to obtain high-quality food at reasonable prices.

Farmer Cooperatives

Farmer cooperatives, their promotion, and their impacts on prices and competition have been issues that will continue through the 1980s. Their performance, condition, and impacts are related to such problems as inflation, energy, transportation, finance, regulation, taxation, antitrust actions, and marketing orders. Also, as capital costs increase, farmers and their cooperatives face problems of acquiring and managing their financial resources effectively. Many cooperatives are small, and since cooperatives exist to provide an alternative in the marketing or purchasing behavior of groups of farmers, the research needs of cooperatives are frequently met in the public sector. Additional research on the factors influencing individual cooperative growth and capital needs, as well as increased access for medium-sized and smaller cooperatives to analyses and procedures for long-range planning, would promote the support of those institutions.

IMPACTS OF THE ADOPTION OF NEW AGRICULTURAL TECHNOLOGIES

While there is generally a strong belief in the United States that there are net social gains from technological advances, there is a real need to be able to anticipate the distributional impacts of each major new technology under consideration. Economists and other social scientists need to involve themselves with scientists of other disciplines to evaluate the different impacts of new technologies before they are adopted, or when new technologies are projected but not yet available for adoption.

WORLD FOOD AND FIBER FORECASTING

The need for improved information pertaining to the domestic and international supplies of food and fiber and about factors that determine the variations in supplies was demonstrated in the 1970s. The 1972 and 1977 Russian wheat production shortfalls and the reduced 1978 Brazilian soybean crop had significant impacts on U.S. commodity markets, farm program costs, and food prices. Data provided by aerospace remote sensing promises to provide improvement in the ability of the Department of Agriculture to discern the domestic and foreign crop situation and outlook.

POTENTIALS FOR INCREASED NONFOOD PRODUCTION

Science and technology are often employed to develop and adapt substitutes or competitors, using agricultural resources, for commodities and materials principally obtained elsewhere. If such substitutes require an increase in the production of an agricultural nonfood commodity or the diversion of resources normally used in food production, they compete for resources normally used to produce food. On the other hand, such competition with domestic food supplies is to some extent lessened if underutilized resources are used to a greater extent. Three areas identified below provide opportunities for nonfood agricultural products to contribute to the development of substitutes for materials obtained by import or from other sources.

Natural Fibers and Renewable Resources

Natural fibers, including wool, cotton, leather, and numerous byproducts from plants and animals, compete directly with manmade fibers, plastics, and chemicals synthesized from natural gas and petroleum. Research provides numerous opportunities to improve the efficiency and reduce the costs of converting renewable farm commodities and byproducts into useful consumer products as nonrenewable sources of basic materials become scarce.

Plant-Derived Industrial Hydrocarbons

Plant sources are the only renewable raw materials that can provide the kinds of hydrocarbons that we now obtain from petrochemicals. Rubber, lubricating oils, pesticides, fertilizers, plastics, and solid, liquid, and gaseous fuels have all been developed from plant raw materials. There is potential for development of a domestic source of natural rubber through increased technology for production of guayule and processing of the resultant latex. Comparative costs do not presently favor plant raw material sources for such products, but the pendulum is swinging in that direction, and time is needed for developing the technology required if plant-derived industrial hydrocarbons are to replace those from traditional sources. Industry is deeply involved in this area in preparation for the projected change in the economic picture.

Energy

Ensuring an adequate supply of energy for national needs while also providing an adequate supply of food and increasing the efficient use of essential materials and products is a major concern. Another concern is how to apply science and technology to strengthen the U.S. international economic position. There are opportunities for scientific and technological contributions that will allow farm and forest enterprises to produce onsite energy from agricultural wastes, to produce and utilize specific crops or materials for energy, to apply energy conservation measures, and to utilize such alternatives as solar or wind energy. Science and technology capabilities can be used to develop and evaluate methods for producing and using energy from farm and forest biomass as a possible substitute for imported petroleum. Methane generators and alcohol stills, for example, provide possible mechanisms for disposing of agricultural and forestry wastes and energy crops. Forest and sugar crop residues are examples of specific biomasses that need to be continually reexamined for energy production potentials in the future. As such energy alternatives are developed, constant attention must be given to the allocation of land and water resources to meet concurrent national requirements for food, fiber, and energy.

RURAL AND COMMUNITY DEVELOPMENT

Rural areas continue to lag significantly behind metropolitan areas by virtually every measure of employment and income. Poverty is considerably more persistent in rural areas, and rural Americans frequently accept a lower level of basic community services in health and medicine, housing, recreation, transportation, fire protection, and public safety. Increases in the number of older rural residents are placing added strains on the already inadequate supply of such services in many areas. Local officials, like those in cities, are faced with growing demands for public services on the one hand and pressures to reduce public expenditures on the other. Major Federal and State requirements for water quality, waste disposal, and handicapped access to public facilities plus rapidly escalating costs of construction and operation are only a few of the complications.

Opportunities exist for research and development of economically feasible technologies and management systems appropriate for providing necessary services in rural areas. Such systems might, for example, be applied to waste treatment and solid waste recycling, transportation services, and microcomputer communications technologies. Similarly, appropriately scaled technology for rural industrial activities holds promise for increasing employment and income opportunities.

A major constraint on the application of scientific and technological capabilities to rural development problems is the inadequacy of the statistical base on rural communities.

REFERENCE

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10 Education*

HIGHLIGHTS

- The application of the new information technologies—computers, video recording devices, and improved means of storing and transmitting information—provides important new challenges for education.
- The new technologies can improve our ability to keep students actively engaged in learning for sustained periods, allow teaching to be adjusted to the rate and style appropriate to each student, and make it possible for students to work on complex real-life problems through computer simulation and graphic displays.
- The Department of Education, working with the National Science Foundation and other Federal agencies, is exploring ways to foster cooperation among educators, scientists, private enterprise, and the various levels of government to help the Nation fully develop educational uses of information technology and distribute them equally to all students.
- The ability of science and technology to contribute to the national welfare rests on two factors: the education of those who choose careers as scientists and engineers, and the education of all Americans who require some understanding of science and technology in their jobs and as citizens.
- Teachers of science and mathematics must be aware of the range of occupational and professional options for their students, of special resources and assistance available for course preparation, and of the uses of computers and communications technologies in teaching.
- In comparison to other industrialized countries, there is a lesser focus on science and mathematics in U.S. school systems. More students are dropping out of science and mathematics courses after the tenth grade than ever before.
- The education of a majority of the adult Americans who have already passed through the educational system has not been adequate to meet their needs in today's technically complex world.
- Some opportunities exist for the Federal Government to influence indirectly science and engineering education at precollege, technical school, and university levels, without impinging on local control.
- Technical training institutions and community colleges need to be integrated into the overall science and engineering education system.

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* Participants in the task group developing this section included representatives of the Department of Education and the National Science Foundation.

- Better use of resources in local industries, colleges and universities, libraries, museums, planetariums, zoos, and nature centers and parks is needed to maximize science and technology education.

INTRODUCTION

In considering the outlook for science and technology in education, two aspects are important. First, science and technology will be making important contributions to the improvement of education through research and development. Federal support of such research and development is concentrated principally in the Department of Education (ED), where the Office of Educational Research and Improvement (OERI) is charged with providing leadership in scientific inquiry into the educational process, and in the Science and Engineering Education Directorate of the National Science Foundation (NSF), which is charged with improving science education at all levels. Those agencies also draw, as appropriate, upon the results of research supported by various biological, behavioral, and social science research programs of the National Science Foundation, the National Institutes of Health (NIH), and the National Institute of Mental Health (NIMH).

Second, education in science and technology for all citizens is centrally important to the strength of the science and technology that underlies our position of world leadership. Education in science is a primary concern of NSF, but a number of other Federal agencies, including ED, the Department of Defense (DOD), the National Aeronautics and Space Administration (NASA), the Department of Energy (DOE), the Department of Agriculture (USDA), and NIH support science and engineering educational activities related to their missions.

RESEARCH AND DEVELOPMENT IN EDUCATION

The most important new challenges and opportunities that science and technology can provide for education in the coming 5 years will center on the new information technologies. The opportunities will be enhanced by the contributions of the relatively new discipline of cognitive science.

Modern electronic information technologies—computers, video recording devices, and inexpensive means of storing and transmitting information—can create a revolution comparable to the invention of printing and the Industrial Revolution. Profound changes are occurring in the ways business and industry are conducted and in the nature of many jobs. Educational curricula should be changed if we are to prepare students to take advantage of the new technologies in their work and in their personal lives. Fortunately, the new technologies create not only new educational needs but also new ways of meeting those needs.

PERSONAL COMPUTERS AND CALCULATORS

Handheld calculators providing the four arithmetic functions plus square root now sell for about $10 (or, combined with a wristwatch, for $30), and the cost of calculators with trigonometric and logarithmic functions has declined to the same level. Calculators able to handle 400-step programs are now about $100. Handheld instructional devices providing drill and games in arithmetic sell for $15 to $25, and devices for spelling drill, with a simulated human voice, sell for $65. Personal computers, which include a TV tube display, keyboard, processor, and a sizable memory, and weigh less than 50 pounds, are now available for as little as $400. They are comparable in capacity to computers that cost hundreds of thousands of dollars a decade and a half ago. They provide graphic displays, some of which are multicolored, which will become increasingly sophisticated and manipulable in the years ahead. Simulated human speech and the ability to accept spoken or typed natural-language commands, answers, and questions will become commonplace.[1]

For the rest of this decade, the computational power of the microcomputer is expected to double every 2 years, with the cost remaining roughly constant. The cost of computer memory will decline rapidly. At the end of the decade, for about 1,000 of today's dollars, we can expect to purchase computers 30 times more powerful than current models and with much larger memory capacity. Today's personal computer is not quite powerful enough to meet many instructional challenges, but the machines of 1985 to 1990 will almost certainly be adequate. However, there is no need to wait until such machines are available to start developing advanced instructional programs to match expected capabilities. Programs created and tested with large machines can be reprogrammed to run on small, inexpensive machines.

VIDEO STORAGE, RETRIEVAL, AND DISPLAY DEVICES

A videodisc system now on the market for $750 provides, in conjunction with a regular TV set, 54,000 separate frames of full-color pictures on one side of a disc similar in size and cost to an LP record. The 54,000 frames can produce 30 minutes of video at 30 frames per second. The system also provides rapid dialed access to each of the frames, which are numbered and can be viewed individually for any length of time. It may provide roughly one quarter of a page of easily legible text on the TV tube or a full page on the new flat display described below. Replay, at regular or slower speed, of any portion of the motion picture is easy.

Combinations of videodisc players and microcomputers, referred to as "intelligent videodisc systems," allow controlled sequencing of video frames, which may be based on student responses. The disc can store 10 billion bits of information (the text of the *Encyclopaedia Britannica* contains 2 billion bits, a human chromosome has a capacity of about 20 billion bits, and the human brain, perhaps 10,000 billion). Digital encoding of information on the videodisc, a technique now being developed, will allow the full capacity to be used so that each frame can store four printed pages or a substantial computer program. One side of a single digitally encoded disc could thus store four hundred 500-page textbooks. Alternatively, a single disc could probably store a copy of all the computer courses ever published.

Discs also have two audio tracks that allow, for example, sound tracks in two languages to be available with motion pictures. The capability of providing up to 30 seconds of sound with each still frame is expected to be available soon. Videodiscs now on the market, like LP records, are stamped from masters and cannot be altered. Several firms are developing videodiscs that will allow erasing and recording by the individual user. Another important development is the high-resolution, flat color display screen that will replace bulky TV tubes that consume large amounts of power. It will provide book-quality print display, make possible a personal computer no larger than an attaché case, and increase the attractiveness of the videodisc as a publishing medium.

COMMUNICATIONS TECHNOLOGY

Various new forms of communication, developed primarily for other purposes, will be increasingly available for educational use. Fiber optics can permit large amounts of information to be sent through glass fibers by laser signals. Thus, access to large collections of information and to distant computers can be provided at reasonable cost. For a few hundred dollars an hour, almost any institution can now send a lecture via satellite to receiving stations thousands of miles away for rebroadcast or for recording on tape for later use. In a few years individual homes will be able to receive such programs directly via a small satellite receiving system that will probably cost about $500.[2] Thus, an engineer in an isolated town in Alaska could study advanced courses from the Massachusetts Institute of Technology (MIT). Satellite systems can also be used to transmit computer programs that can be recorded and used to enrich students' interaction with transmitted lectures. The use of cable TV distribution will allow the noncapital costs of administration and equipment maintenance to be met with a televised enrollment as low as 40 students in a single course offering, and two-way cable will allow the students to communicate with the instructor.

COGNITIVE SCIENCE

Cognitive science—the science of human mental processes—is a rapidly growing interdisciplinary movement involving psychologists, computer scientists, philosophers, anthropologists, linguists, and educators. Glaser, in discussing the contributions of psychology to education, has pointed out, "At the present time, modern cognitive psychology is the dominant theoretical force in psychological science as opposed to the first half of the century when behavioristic, antimentalistic stimulus-response theories of learning were in the ascendance."[3] He goes on to say, "The internal cognitive world of complex human behavior involved in thinking, problem-solving, acquiring understanding of various domains of knowledge, and personal expectations and self-development . . . which have been only peripheral aspects of . . . behaviorist psychology, now are the starting points for cognitive psychologists." Newell and Simon[4] describe this change as follows:

> For several decades psychology . . . focused on learning, lower organisms, and tasks that are simple from an adult viewpoint. Within the last dozen years a general change in scientific outlook has occurred. One can date the change roughly from 1956: in psychology, by the appearance of Bruner, Goodnow, and Austin's *A Study of Thinking*[5] and George Miller's "The magical number seven"[6]; in linguistics, by Noam Chomsky's "Three models of language"[7]; and in computer science, by our own paper on the Logic Theory Machine.[8]

This shift in emphasis is significant for educational research and development and therefore ultimately for education itself. In the past, many teachers and persons in the disciplines concerned with the substance of education were unable to take seriously behaviorist psychology's seemingly simplistic view of what is to be learned and how it is to be learned. The new cognitive psychology accords much more closely with common views of teaching and learning, while at the same time providing a scientific basis for improving our understanding of these processes and thus for improving education.

Cognitive science is beginning to be applied directly to education in a number of ways. Reading comprehension is coming to be understood as a fitting of what is being read to the content and conceptual structure of the reader's existing knowledge rather than as an isolated assimilation of new information. The nature of mental processes involved in solving problems in mathematics and science by both novices and experts is being elucidated, and we can expect better means of learning and teaching problem-solving skills. The subtle processes of self-monitoring and self-control that are common to skills in comprehension, problem solving, and learning of complex knowledge are being studied in a burgeoning branch of psychology called metacognition. Teaching children to monitor their own comprehension and to take action when they do not understand, an ability which is characteristic of skilled readers, is proving to be a powerful instructional technique. A fuller discussion of cognitive science and learning can be found in the National Research Council's contribution to this *Five-Year Outlook*.

Computers have played a central role in cognitive science from the start. Those scientists in the field of artificial intelligence who seek to create machines that carry out intellectual tasks in the same way that human beings do have an obvious interest in understanding human intellectual processes. Conversely, scientists whose primary concern is understanding human intellectual processes have found computer simulation of those processes a powerful technique for creating and testing models of the methods people use to perform complex tasks. Thus, a number of scientists are expert in both cognitive psychology and computer science, and this group of individuals provides an important resource in the application of the new technologies and the new cognitive science to education.

APPLICATION OF TECHNOLOGY TO EDUCATION

The new technologies can substantially improve our ability to keep students actively engaged in learning for sustained periods, a prime requisite for effective education, and can allow teaching to be adjusted to the rate and style appropriate to each student and to the particular difficulties a student encounters. During the last decade the effectiveness of computer aids to instruction has been established, even though those aids used computer programs that are regarded today as primitive. The experience we have gained and the much lower cost of computer power now make considerably more sophisticated programs possible. The efficacy of such educational television programs as "Sesame Street" and "The Electric Company" is also well established.

In addition to these extensions of conventional education, current and expected technologies will open up important new possibilities. Through the computer and the graphic displays it can generate, we can simulate the behavior of such objects as satellites, balls, electrons, and pendulums, and of biological and chemical systems under conditions that can be controlled by the student, thus allowing a form of exploration. Adaptations of simulation trainers for airplane pilots can help students develop a variety of complex skills. Instruction can be made more attractive to students, and thus more effective, by being cast in the form of games.[9]

Word processors, which allow easy creation and editing of text, can be coupled with instant-access computerized dictionaries, creating a system which can develop facility and coherence in writing.[10]

New computers allow us to go beyond the traditional multiple-choice test, which is based on half-century-old scoring techniques, toward tests for performance in the solution of complex problems. Computer-based testing can present problems more realistically, allow a student to proceed even when an arithmetical error is made, follow and evaluate the student's problem-solving procedures, and provide guidance to the teacher and the student on how to improve performance.

Videodiscs can provide easy access to a wide range of historical, cultural, and artistic still and motion pictures and written materials. Indeed, these new technologies make feasible a new type of encyclopedic textbook with which the student, sitting at a console, can explore a domain of knowledge in degree of detail suited to his or her particular interests. Communication links can provide instant access to the card catalogs of major libraries. Eventually, the texts of many journals and books may be available by allowing computer access to the encoding involved in electronic typesetting. Using the new technologies will help prepare students to use those technologies effectively in their jobs and personal lives.

The computer can make it possible for physically handicapped persons to engage in a wide variety of learning activities. Computer programs that can interpret spoken words put important robotic functions at a paralyzed person's disposal. Special keyboards or controls can enable an individual with limited muscular control to engage fully the power of the computer and thereby participate in such learning and creative activities as writing, problem solving, and designing. Optical character readers can convert almost any printed page into tactile signals that a blind person can read.[11] Most kinds of visual information can be given a surface texture so that maps and geometric figures can be sensed by touch.[12] Words and numbers can be converted into synthesized speech so that a blind person will have the choice of listening to or "touch reading" any printed or computer-stored document. The blind student will not need a special typewriter to compose essays that both blind and sighted people can read. Analogous technological devices can be prepared for many handicaps, making it possible to mainstream handicapped children and accommodate the resulting diversity of students through individualization.

ACHIEVING THE POTENTIAL OF TECHNOLOGY IN EDUCATION

There is considerable interest among State and local education authorities, educators, publishers, and equipment vendors in pursuing educational use of the new technology. In 1978 the new possibilities were the subject of extensive hearings by a subcommittee of the House Committee on Science and Technology, and in 1980 the House Subcommittees on Select Education and on Science, Research, and Technology held joint hearings on the same topic. Those hearings revealed widespread agreement that properly implemented uses of computer technology in the schools can make significant improvements in teacher effectiveness and student learning. They also found agreement that the microelectronics revolution will probably make personal computers commonplace in the home in the near future and will dramatically reduce the cost of general purpose computer systems, thereby creating a unique educational opportunity for the school and the home. The Secretary of Education and the Director of the National Science Foundation, in their report on the status of science education,[13] stressed the importance of the computer in science education for all Americans. The Office of Technology Assessment, at the request of the chairmen of the House Subcommittees on Select Education and on Science, Research, and Technology, has undertaken a study assessing the possible impacts of the new technologies on education.

There are two overriding questions of great national concern. Will the great educational potential of the information technology revolution be realized soon? Will it be inadequately realized or greatly delayed by too rapid expansion followed by disillusionment? Will the benefits of this revolution be equitably distributed? Or will students in well-to-do homes and schools be its principal beneficiaries, a situation which would widen the gap between them and economically less fortunate students? The Department of Education is giving high priority to seeking ways to help State and local systems achieve both full development of the educational uses of technology and its equitable distribution.

Late in 1980, the Secretary of Education established a departmentwide Task Force on Learning and Electronic Technology to study and report on opportunities, important problems and constraints, and appropriate ways that the Department, in cooperation with others, can help overcome problems and constraints and achieve the promise presented by the new technologies. The Task Force is conferring extensively with educators, private enterprise, and other government agencies. Actions proposed will take into account and build upon current activities of ED and NSF. The National Institute of Education (NIE) has established an external task force to recommend the most promising directions for research and development on the application of information technology to the teaching and learning of reading and writing. ED continues to help support the development of educational television programs like "Sesame Street," "The Electric Company," "Villa Allegre," "Freestyle," and "3–2–1 Contact," and the adaptation and augmentation of such programs for the videodisc. ED's Office of Special Education and Rehabilitative Services continues a strong program of developing technological aids for the handicapped. NIE is supporting a study of factors that influence the adoption and use of technology in schools; the results of this and other studies, including organization-science studies of factors fostering and hindering innovation in schools, will be considered in the emerging ED programs in technology.

Realization of the potential of technology for education and its equitable availability will require the continuing cooperation of educators, researchers and developers, private enterprise, and government at all levels over the next decade. Prospects for such cooperation appear good.

EDUCATION IN SCIENCE AND ENGINEERING

Although the mission of education in science and technology has historically focused on the process of identifying and nurturing talented students for careers as scientists and engineers, more recently it has become evident that the ability of science and technology to contribute to the national welfare depends not only on a competent work force but also on informed decisions of an educated public. The American public must have scientific and technological information to better understand the costs, risks, and benefits associated with technological advances that have immediate impact in such areas as agriculture, energy, environment, defense, and transportation. In short, education in science and technology must include both the education of those who choose careers as scientists and engineers and the education of the American public in general.

Because of the critical role of education in science and technology and its relation to the missions of many agencies, substantial support for special-purpose programs can be found throughout the government. The following discussion provides a perspective on the needs and concerns of various Federal agencies in education in science and technology. Situations that may warrant special attention within the next 5 years are described. Similarly, current and emerging problems of national significance are identified, and opportunities for their resolution are detailed.

PROBLEMS IN EDUCATION IN SCIENCE AND TECHNOLOGY

In February 1980, NSF and ED conducted a cooperative study to determine the Nation's needs in science and engineering education. The report identified a number of areas that are in need of attention:

(1) Today, people in a wide range of nonscientific and nonengineering occupations and professions must have a greater understanding of science and technology than at any time in our history. Our education system does not now provide such understanding.

(2) More students than ever before are dropping out of science and mathematics courses after the 10th grade, and this trend shows no sign of abating.

(3) The lack of focus on science and mathematics in our school systems is in marked contrast to other industrialized countries. Japan, Germany, and the Soviet Union all provide rigorous training in science and mathematics for all their citizens.

(4) The content of secondary school science and mathematics courses does not meet the needs and interests of those students for whom the courses will be their entire formal scientific education.

(5) There is a shortage of mathematics and physical science teachers in the Nation's secondary schools.

(6) There is a lack of suitable laboratory facilities at the secondary school level.

(7) There has been a decline in financial support for development of mathematics and physical science teachers.

(8) The education of a majority of the adult Americans who have already passed through the system has not been adequate to meet their needs as citizens in today's technically complex world.

(9) Shortages of trained personnel exist in the computer professions, and in chemical, electrical, industrial, and most other fields of engineering.

(10) There are shortages of qualified faculty members in most fields of engineering and in the computer professions.

(11) There is a severe lack of the equipment needed for engineering education at the undergraduate level.

(12) Continuing education and retraining are essential in science and engineering, where technical advances are constantly creating new knowledge and new fields and opportunities. At present, continuing education of industrial engineers and scientists is spread among a variety of sources including private entrepreneurs, industrial firms, professional societies, and colleges and universities, with little or no coordination.

(13) Technical training has largely been a haphazard enterprise, accomplished by a combination of on-the-job training, a few technical institutes, and vocational training in secondary schools. There is a need for technical programs to be integrated into the overall science and engineering education system to better attract and train the technicians needed to ensure the success of the Nation as a technical society.

(14) Women, minorities, and the physically handicapped continue to be underrepresented in the science and engineering professions.

The needs that were identified in the report provide opportunities for new initiatives in education in science and engineering. Those opportunities are outlined in the pages that follow.

OPPORTUNITIES TO FACILITATE EDUCATION IN SCIENCE AND ENGINEERING

Although education is the direct responsibility of State and local governments, the Federal Government can indirectly influence science and engineering education. Agencies support science and engineering education by funding facilities and equipment for instruction and research in our Nation's colleges and universities and by providing fellowship, traineeship, and training grant support. Additionally, support is provided for such activities as technical conferences, teacher institutes, faculty development, course development, and nonspecific or generalized purposes related to scientific research and education.

The Federal Government also indirectly affects science and engineering education through mission-related activities of the various agencies that may include: use of Federal agencies and resources, employment of students and researchers, the dissemination of science and engineering information that can be used for educational purposes, and a variety of other mechanisms that affect science and engineering education. The discussion of programs that follows is intended to give a perspective of what agencies can do in science and engineering education.

An innovative program being sponsored by the National Aeronautics and Space Administration, the Space Shuttle student involvement program, is an example of a promising opportunity. The program is an annual nationwide competition, conducted in grades 9-12, that urges students to propose scientific and engineering experiments to be performed on the Space Shuttle. The aim is to increase student interest in science and foster career development.

Other opportunities to use existing resources and capabilities in science and technology education are found in programs that allow students to use research centers and Federal laboratories to conduct thesis research. Again, the intent is to increase the number of highly trained scientists and engineers and to encourage students to consider careers in laboratories and research centers. Such programs are usually operated by DOD, NASA, DOE, NIH, and other agencies and departments.

Employment of students in laboratories and research centers affords another promising opportunity. A working model is the Research Apprenticeship Program for Minority High School Students (RAMHSS). RAMHSS uses existing activities to involve scientists, mathematicians, and engineers in the educational process. Through the program, minority high school students are employed as research apprentices in universities, health professional schools, hospitals, Federal laboratories, and other research centers.

Student employment and assistance through grants to institutions or to specific research projects also help develop the scientific and technical personnel base. For example, the Department of Energy provides traineeships to increase the number of graduates in energy-related engineering fields, where there are critical needs. Similarly, the National Institutes of Health provides support, in the form of National Research Service Awards, for research training in the biomedical and behavioral sciences. The Department of Defense also offers a number of initiatives at both the undergraduate and graduate level for developing the scientific and technical personnel needed for defense-related employment.

Another education program that could promote careers in such areas as health science and health technology is operated by the Department of Agriculture. Agricultural extension services have an educational system that reaches into virtually every county in the United States and its territories. Current programs address such national concerns as nutrition education, pest management, pollution, energy conservation, management of private forest land, and the needs of the agricultural community. Career development programs in health science and health technology seem to be a logical next step.

NEEDS IN ELEMENTARY, SECONDARY, AND POSTSECONDARY EDUCATION

The ability of education in science and technology to accomplish the goals addressed in the NSF/ED report will necessarily depend upon the attention given to identified needs in the schools, colleges, and universities, and to the communication of scientific and technical information to the public.

New teaching materials in science and technology are needed for the broad spectrum of elementary and secondary students, and special emphasis should be placed on the needs of minorities, women, and the physically handicapped. Likewise, strategies for making optimal use of the resources available in local industries, colleges and universities, libraries, museums, planetariums, zoos, and nature centers and parks are needed. Also, secondary school students, teachers, and counselors should become more aware of the range of occupational and professional options that require adequate preparation in mathematics and science.

To encourage secondary school students to take more mathematics, additional efforts by State and local education agencies to develop mathematics courses appropriate to the broad range of students are needed. Expanded enrollment in high school mathematics would increase the career options available to high school graduates.

There are already a number of programs that aim to identify students with special talent for science and mathematics during their early adolescent years and offer them opportunities to develop their interests in those areas. Such programs could include summer workshops in community and industrial settings, plus followup activities in the schools.

Attention must also be given to the needs of teachers. State and local programs that speak to those needs can be focused more sharply on science, technology, and mathematics instruction. Such programs of State and local education agencies provide resources and assistance in course preparation and in resolving day-to-day problems encountered in teaching science, mathematics, and technology. The programs offer superior teachers a format for sharing insights with their less experienced colleagues both locally and throughout the Nation.

The establishment of regional centers by State and local education agencies provides still more opportunities for educational initiatives in science and technology. Regional centers established jointly by State and local governments and private industry could make science and technology equipment, including personal computers, available to schools.

Inservice and summer institute programs and short courses sponsored by State and local agencies are another approach to introducing experienced science and mathematics teachers to new curricula and the uses of computer and communications technology, and to upgrading the skills of less qualified teachers. Such programs could be supported jointly with industry and could offer teachers experience in industry as well as in the more traditional settings.

There are additional opportunities to increase familiarity with the variety of possible careers in science, mathematics, and technology. Scientific and technical careers could be promoted by State and local education agencies and the private sector through vocational course material. Emphasis could be placed on detailing the occupational opportunities available to secondary school graduates with good qualifications in science and mathematics.

Beyond the elementary and secondary school years, technical training institutions and community colleges could be integrated by State and local agencies into the science and engineering education system so they can improve their effectiveness in attracting and training the technicians needed to ensure our continued success as a technological society. Similarly, the role that technical training institutions and community colleges have in increasing public understanding of science and technology needs greater articulation.

Technical schools and community colleges could provide a range of adult education courses aimed at increasing the public understanding of science and technology, especially in relation to local and regional issues of science- and technology-related public policy. Further efforts could be made to help science and technology museums, planetariums, zoos, and nature centers and parks improve their capabilities to foster public understanding of science and technology. State and local programs that provide general support to museums and public libraries could be focused more sharply on public understanding of science and technology.

At the undergraduate and graduate level, perhaps the greatest constraint on quality science and engineering instruction is the lack of modern instructional equipment. Yet, this constraint presents the opportunity for closer cooperation between industry and universities through the sharing of research instrumentation. Expanded university-industry cooperation could stimulate and enhance university research and make its results more accessible to industry.

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11 International Affairs*

HIGHLIGHTS

- U.S. science and technology programs with other countries help to maintain an international perspective of U.S. leadership among nations as they increase our ability to combat global problems.
- World population is expected to increase by 50 percent by the year 2000, with 90 percent of the growth occurring in Third World countries. Improved health care services and attention to family planning and contraceptive technology are necessary. International cooperation in agricultural science and technology will help meet increasing demands for food. Efforts must be made to adapt technologies to the specific socioeconomic conditions of developing nations.
- The United States is involved in programs with many nations to develop additional energy sources. At the same time, conservation of forest, water, and mineral resources requires international cooperation. Attention to the unique problems of arid lands and to global weather and climate effects is necessary.
- The oceans nurture a tremendous variety and quantity of living resources and hold great promise for providing minerals, hydrocarbons, and alternative sources of energy. Jurisdiction of ocean resources is a serious issue. A similar concern exists in the development of resources in the polar regions.
- Pollution problems transcend national borders, requiring extensive international efforts in research and control measures. The buildup of carbon dioxide in the atmosphere, depletion of the stratospheric ozone layer, pollution of the marine environment, and waste disposal should receive particular attention.
- The free flow of information and ideas, fundamental to American culture and society, disconcerts some nations. In addition, advances in telecommunications that result in crowding of the radio frequency spectrum and of geostationary orbit space raise regulatory concerns. Peaceful use of outer space, another "common resource" of mankind, provides many opportunities for cooperative efforts.

INTRODUCTION

There have been enormous changes in science and technology in the past three decades. Those changes affect all areas of life, transcend national boundaries, and may be expected to accelerate in the next 5 years, offering both new problems and new opportunities for U.S. foreign policy. Growing problems of scarcity and distribution of life-sustaining resources—food, energy, water, and health services—in the face of population increases could destabilize political and economic institutions, both internally and externally. The advancement and diffusion of technology will likely create new problems and issues, such as those associated with energy development, industrialization, and international communication, even as they solve old ones. Those problems and others like them are global in their scope and implications, and they can be tackled effectively only through international cooperation.

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* Participants in the task group developing this section included representatives of the Department of State and the Agency for International Development.

Advanced nations on the threshold of high-cost, high-risk, "Big Science" projects will need to pursue closer cooperation to advance the frontiers of science in space, alternative sources of energy, medicine, earthquake prediction, and other areas of international concern. The demands of developing nations to share in the benefits of scientific and technological advancements for building their own economic infrastructures are almost certain to increase. Some of those nations are important suppliers of oil and minerals to the more developed countries; some are sources of political instability.

The nature of the U.S. involvement in world affairs has changed significantly since the end of World War II. Traditional power relationships have given way to an emphasis on interdependence. Increases in the price of our major energy source, oil, are but one manifestation of that growing interdependence. Consciousness of both the promises and limits of technology has risen in the United States and abroad. Resources still seem abundant, but their uneven distribution gives rise to new opportunities for both cooperation and conflict over rights of access.

U.S. science and technology programs with other countries serve important foreign policy functions. They help to maintain an international perspective of U.S. leadership among nations. They increase our ability to confront such global problems of international concern as malnutrition, prevention of disease, environmental pollution, and resource degradation. They assist the United States and others in meeting food, shelter, and energy requirements, and they provide essential ingredients for future economic and social development.

Scientific and technological cooperation can also help create an international political environment in which collaborative research and development can flourish. It opens up objective scientific interchange which can help bridge political, ideological, and cultural gaps between the United States and other countries. Bilateral and multilateral science and technology agreements can be instrumental in providing access to information about scientific, technological, economic, and political developments abroad, and concurrently help to forge links among the countries involved. Science and technology (S&T) can also be expected to play increasingly important roles in global economic and social development programs. U.S. policy encourages the growth of the economies of developing countries through the strengthening of their S&T infrastructures.

SCIENCE AND TECHNOLOGY FOR DEVELOPMENT

The recent Department of State and Council on Environmental Quality *Global 2000 Report to the President* projected late 1970s trends into the future, barring any dramatic technological innovations. The major conclusions of that study reinforced those of other recent analyses, such as the *World Conservation Strategy*, which point to a number of high priority emerging problem areas in which science and technology can play a major role in the years immediately ahead. For example, the *Global 2000 Report* projects a dramatic (50 percent) population growth by the year 2000, particularly in the Third World. Gross National Product (GNP) per capita will likely remain low in the developing nations. At the same time, food production by 2000 will increase by only 15 percent worldwide on a per capita basis (including developed countries) on a projected 4 percent increase in cultivated land. Regional water shortages are projected to become more severe, as demand will double in nearly half the world due to population growth.

If current rates of cutting continue, forests could be depleted by 40 percent worldwide. Most of the loss will occur in the tropical forests of Africa, Asia, and South America. Agricultural soils are continuing to deteriorate due to erosion, loss of organic matter, salinization, desertification, water logging, and alkalinity. Carbon dioxide (CO_2) is increasing in the atmosphere to concentrations that could alter weather patterns by the middle of the 21st century, and the combustion of fossil fuels, particularly coal, contributes to acid rain that may damage lakes, soils, vegetation, and buildings. Finally, the ozone layer, which protects humans from cancer-causing ultraviolet light, could be threatened by the buildup of chlorofluorocarbons.

Many of these effects will be felt heavily in the developing nations, where standards of living are already low. More broadly, the global ecosystem will suffer changes that could result in a decline in the quality of life in the richer nations. Better ways must be found to cope with and solve these extremely complex and difficult problems, including the more effective and efficient application of the tools of science and technology.

POPULATION

Rapid population growth is a fundamental cause of many of the emerging economic, social, and political problems confronting mankind. It is a major hindrance to economic development plans in less developed countries (LDCs), often shrinking or threatening to consume significant gains in income that would otherwise result from those plans. Attempts to improve the level and distribution of health care in LDCs are also negatively affected.

High growth rates play a key role in urban and rural development, labor force standards of living, education, and a wide range of other social and cultural problems. If a country has a relatively young age structure, its population will grow very rapidly for several decades, even after the rate of new births has been reduced to the replacement level.

A greater emphasis on family planning aimed at a significant reduction in population growth rates is essential for dealing with the problems mentioned above and the political instability they generate. Additional biomedical research into new contraceptive technology and its safety and convenience is needed. Most U.S. biomedical research in fertility control is conducted by the National Institutes of Health Center for Population Research. While U.S. Government action is implemented abroad largely through the agencies directly concerned with economic development and foreign affairs, such other agencies as the Department of Commerce, the Department of Housing and Urban Development, and the Department of Health and Human Services deal with social and economic issues that are affected by population growth. The largest multilateral assistance program for population issues is the United Nations Fund for Population Activities.

FOOD SUPPLIES

U.S. policy has consistently stressed strong bilateral cooperation in agricultural science and technology as well as comparable multilateral development efforts. Intermediate objectives include support for the Food and Agriculture Organization, International Fund for Agricultural Development, Consultative Group for International Agricultural Research, World Food Program, World Food Council, and international grain reserves programs.

The Department of State has assumed special responsibilities involving science and technology in agriculture. It works with the Department of Agriculture, for example, on international cooperative programs with Mexico on new crops, arid lands, agricultural productivity, guayule (native latex) development, and plant genetics/germplasm exchange. Several interagency committees focus on science and technology in agriculture. One example is the Interagency Plant Sciences Committee.

The U.S. goals include assisting the developing nations in improving their food production capabilities; reducing foreign dependence on U.S. food aid; improving the management of the agricultural resource base on which food production depends; mitigating the complex political, economic, and social problems that result from inadequate global food supplies; and encouraging energy efficiency in agricultural production.

Plant pests and food spoilage, major reasons for reduced food supplies, require greater attention. Research is also needed in new crop development, including innovative organizational and administrative approaches, particularly in delivering fertilizers and water to farmers and distributing and storing farm products. Although the United States can supply technological and scientific expertise as well as some agricultural development aid, increases in global food supplies will depend ultimately on actions of the developing nations themselves. Such increases will entail larger investments in the generally neglected rural sector, land reforms, and improved research and extension efforts.

INFRASTRUCTURE

In order to apply science and technology to Third World social and economic development, the resources of the industrialized world, and especially its capacity for scientific and technological research, need to be brought to bear on the problems of developing nations. Countries of the Third World face language and institutional barriers and suffer from a lack of skilled manpower which frustrates their ability to absorb and adapt scientific information and foreign technology. Their technology choices need to be adapted better to their own socioeconomic conditions. For example, most require innovative "capital-saving" (and labor-using) technologies that can provide needed employment opportunities, or capital-intensive industries to manufacture labor-intensive tools (such as better farm implements and hand tools) to take advantage of large, unskilled populations and to make each laborer more productive.

Appropriate Technology International, a private, nonprofit institution mandated by Congress and funded by the Agency for International Development (AID), supports innovative and low-cost activities that encourage local self-reliance. Through grants, loans, and technical information and assistance, organizations in developing countries can improve their ability to test and promote technologies and processes that fit the income, skills, culture, and customs of a particular area. The World Bank, the United Nations Development Program, and, more recently, the U.N. Interim Fund for Science and Technology for Development are among the major multilateral programs supporting the development of scientific capabilities in Third World countries.

It is also important to stimulate research activity in the Third World. Building scientific and technological capacity requires paying attention to the functions and institutions that stimulate scientific research and technological innovation. Industrial research laboratories, national scientific organizations, and economic planning agencies can be elements of a more fully developed scientific capacity, but to establish them will require the assistance of the international scientific community.

ENERGY AND NATURAL RESOURCES

ENERGY SOURCES

Over the next decade U.S. reliance on imported oil may be reduced through the development of U.S. coal, greater exploitation of domestic petroleum reserves, and intensive efforts at conservation. In the longer term, however, it will be necessary to bring about a transition to more abundant and secure sources of energy.

The United States is involved in a number of bilateral and multilateral programs to accelerate the commercialization of both new energy technologies and nuclear power. The multilateral programs include the United States as a leader in R&D projects under the aegis of the International Energy Agency (IEA) and a similar role in the Organization for Economic Cooperation and Development (OECD)/IEA High Level Group on Energy Technology Commercialization. The High Level Group, building on the work of the International Energy Technology Group, has recommended: (1) a phased approach to new energy technology commercialization; (2) review and, where appropriate, restructuring of government regulations and policies related to commercialization; (3) utilization of a variety of national measures to create energy technology options during the 1980s; (4) facilitation of opportunities for international cooperation to accelerate the solution of energy R&D problems; and (5) monitoring and assessing the effectiveness of measures taken to encourage commercialization.

An ideal energy source should be abundant, secure, reasonably priced, clean, and safe. Science and technology in many countries can help make existing sources meet those criteria better and can help to develop new sources with more of those characteristics. Increased attention must also be given to commercialization of new technologies. Development of commercially available fuels from biomass is already under way in several countries. Exploration of solar energy and liquid fuels from shale, tar sands, and heavy oils has already begun in some cases, but will require added research and investment. Commercialization is certain to involve major economic costs and may have health, safety, and environmental impacts on a global scale. Appropriate government research is required to help mitigate some of the global risks.

FOREST RESOURCES

Tropical forests are rapidly disappearing. Continuing loss will affect watersheds and the availability of certain woods. It will undercut development projects (for instance, water resources) in which the United States is investing and accelerate the rate of extinction of tropical plants and animals. It could also cause changes in weather and climate, possibly on a global scale. A recently published report to the President defined several important scientific and policy goals on tropical forest management for the immediate future. The United States will seek commitments from all countries and international and regional organizations to provide for sound tropical forest management. Research should include a world analysis of the rates and causes of tropical forest loss; forest management techniques, ecosystem dynamics, commercial forestry efficiency, and economic use of forest products; and major international programs to inventory, evaluate, classify, and catalog unique forest plant and animal types.

Several U.S. Government agencies will play important roles in that effort over the next several years. The National Science Foundation and the Smithsonian Institution will work on research; AID and the Peace Corps, on development assistance; the Departments of Commerce and State, on economic aspects; the National Oceanic and Atmospheric Administration, on monitoring; and the Departments of the Interior and Agriculture on ecological monitoring.

WATER RESOURCES

Water availability is, and will continue to be, a major determinant of the direction and pace of economic and social development everywhere. Considerations of both quantity and quality are involved. Beyond purely domestic issues, U.S. interests focus on our relationships with Mexico and Canada and on our development assistance efforts overseas as well as international disputes and conflicts over water resources that may have political and economic impacts on the United States.

Shared problems with Canada include pollution of the Great Lakes by industrial and residual wastes. With Mexico, the Rio Grande and Colorado River salinity problems persist, and U.S.-Mexico relationships are exacerbated by increasing problems of ground-water exploitation and water pollution from urban sewage.

U.S. objectives are to develop the management capabilities to optimize the long-term use of water resources, lessen the potential for conflict within and among nations through broader information exchange on management approaches and negotiation of treaties and agreements, and expand research and development to identify potential threats to water resources and develop water-conserving alternatives to present management approaches.

Over the next 5 years we anticipate significant improvement in capabilities for locating underground water, desalting brackish ground water and sea water, and increasing the efficiency of water use in agriculture and industry. At the same time, legal and political issues over the use of shared water resources, pollution, and water diversions are quite likely to grow rapidly.

ARID LANDS MANAGEMENT

Ecological changes that destroy the vegetative cover and soil fertility in arid and semi-arid lands continue to accelerate as increasing populations in dry regions put more pressure on the land to meet needs for livestock range, cropland, and fuelwood. The United Nations has identified about 2 billion hectares of lands worldwide where the risk of desertification is "high" or "very high." The total land so identified is 2½ times larger than areas now classified as desert. Control of the desertification process is necessary if famine and extreme human dislocations are to be avoided.

The U.S./Mexico Agreement on Arid Lands Management and Desertification Control established a joint program to combat desertification in the border zone. The United States has expanded its bilateral development assistance program in areas related to desertification, including alternatives to firewood, reforestation and remote sensing applications in arid lands, and desertification monitoring and assessment. We have expanded research in such areas as salt- and drought-tolerant plants, commercial development of various arid lands plants, new technologies and management techniques for watersheds and rangelands, and improved techniques for water harvesting. Opportunities for science and technology to contribute include the design and funding of research and development on crops and vegetative coverings tolerant of various soil types, greater economic use of naturally occurring arid lands plants, rehabilitation of degraded lands, use of saline water in agriculture, introduction of operational desertification monitoring techniques, and management of surface and groundwater reservoirs.

U.S. Government objectives are to improve our own land use policies and encourage other nations to use arid lands more efficiently, i.e., to manage water resources, increase soil fertility, reduce grazing pressure, and plant crops suited for arid and semi-arid conditions. The United States has participated in a variety of efforts designed to control desertification. An interagency committee, chaired by the Department of State, coordinates U.S. programs and positions in this area, both with respect to U.S./Mexico bilateral cooperation and U.S. participation in the Global Plan of Action on Desertification being administered by the U.N. Environment Program.

MINERAL RESOURCES

Demands for raw materials will continue to increase as more countries develop their economies and as those economies become more complex. At this time, there is no physical shortage of most minerals. However, the long lead times required for minerals production can produce future shortages of production capacity if current investment levels are too low. U.S. objectives are to ensure adequate long-term supplies of mineral raw materials essential to the industrial base of the United States and our allies, and to reduce dependence through conservation, recycling, use of substitute materials, development of domestic resources, and diversification of import sources. Instability of some producing areas could lead to supply interruptions. Dependence on such areas for minerals can be reduced by developing alternative sources of supply. New techniques of resource discovery, extraction, processing, and remote sensing will be used to locate and manage natural resources.

WEATHER AND CLIMATE

The United States has been involved broadly in the development of weather sciences in recent decades. Satellite sensors provide synoptic views of large-scale weather systems. A network of Earth-based sensors provides information on a more detailed scale. Considerable advances have been made, particularly in long-range and medium-range forecasting, and the use of high-speed, powerful computers should bring future predictions of greater accuracy based on rapid analysis of pressure and temperature data from around the globe.

Weather modification research has been conducted for some 50 years in this country. The potential benefits of modification make it of continuing interest, even though it is not yet certain that it can be safely used in all its forms. Progress is slow, partly because the research is difficult, and benefits and risks have to be balanced. International guidance and controls are likely to be a matter of increasing concern during the next 5 years. As the relationships between climate and other factors become better understood, cooperative research efforts could be focused on weather modification. The U.S. 5-year National Climate Program Plan emphasizes early production of useful data and information based on our existing knowledge of climate in addition to expanding our understanding of its impacts on society.

The World Climate Program, launched by the World Meteorological Organization in 1979, is similar to the U.S. program in data, applications, impacts, and research. The Department of State supports the objectives of both programs and is attempting to encourage coordination and mutual reinforcement of activities wherever feasible. The objective is to develop a greater understanding of climatic processes and to lessen adverse climate effects on world agriculture and on the atmosphere and oceans. During the next 5 years we should improve our understanding of weather phenomena and climate changes by expanding opportunities for gathering information on a global scale.

OCEANS AND POLAR AREAS

OCEAN RESOURCES

In addition to playing a central role in the dynamics of the world's weather and climate systems, the oceans of the world nurture a tremendous variety and quantity of living resources. They are, however, finite, and certain species have been so depleted that their use is no longer economical. Many nations are heavily dependent on the oceans for food, and some have adopted fishing practices that threaten certain species or that interfere with the fishing activities of other countries. The trend is toward the coastal nations extending their jurisdiction over living resources in adjacent ocean areas. Because that will permit greater domestic control of fishery resources, it holds promise for improving the ocean's productivity in the long run, but it is also likely to compound problems of access and effective international management of stocks that move across boundaries.

The oceans hold great promise for mineral and hydrocarbon production and for providing alternative sources of energy. One of the most exciting prospects is the recovery of polymetallic nodules containing such critical minerals as copper, manganese, and nickel from the floor of the deep seabed. The United States is continuing to encourage the development of deep seabed mining technology and the possible regulation of such mining through appropriate international arrangements. Perhaps as long as a decade will be required before commercial mining of deep seabed minerals is feasible. Until that time, we are working with other nations to coordinate preparatory ocean mining activities.

Further developments in undersea technology could make it an important foreign policy concern in the next 5 years. Offshore oil production continues to grow and to require increasingly complex and costly technology. The United States also hopes to help identify and develop other minerals or potential energy sources from the oceans. Ocean thermal energy conversion will be an important part of our marine research effort, requiring continuing cooperation among NOAA, the Department of Energy, and other Federal agencies. Wave power and ocean currents are other possible energy sources.

We also anticipate that our increasing ability to understand the ocean and monitor changes in it will improve our capacity to manage its living resources. The United States cooperates with other nations in such bodies as the International Council for the Exploration of the Seas, UNESCO's Intergovernmental Oceanographic Commission (IOC), and the Food and Agriculture Organization (FAO) to promote international programs aimed at increasing the ocean's yield of food. The United States has also been instrumental in inaugurating the Ocean Science in Relation to Living Resources program under which IOC and FAO will cooperate to gain a better understanding of marine ecosystems as they relate to the practical development of fisheries.

POLAR REGIONS

The Antarctic and, more recently, the Arctic have come to be perceived as distinct regions with unique environmental, resources management, economic, and political characteristics. Both regions exercise significant influence on global marine and meteorological processes. They support uncommon and, particularly in the case of the Antarctic, productive ecological systems. Both regions offer unequaled opportunity for scientific research and are the subjects of increasing interest for their mineral resource potential.

The United States supports the establishment of international agreements to deal with resource questions in the Antarctic. That objective aims not only at the wise management of existing or potential resources and the protection of the Antarctic environment, but also at maintaining the system of international cooperation that has evolved under the Antarctic Treaty system. In the Arctic, we seek resolution of boundary and other jurisdictional disagreements with our neighbors and, where necessary, arrangements to deal with the transboundary effects of increased human activity.

During the next 5 years, emphasis will be on the entry into force and effective startup of the Convention on the Conservation of Antarctic Marine Living Resources and negotiation of an international regime to deal with possible mineral resources activity in Antarctica. The United States will also pay close attention to its scientific research priorities in Antarctica. In the Arctic, an Interagency Arctic Policy Group has been reinstituted to identify U.S. interests there and to provide a mechanism for coordinating necessary action in pursuit of those interests.

ENVIRONMENT AND HEALTH

ATMOSPHERIC POLLUTION

A number of serious pollution problems transcend national borders, requiring extensive international cooperative efforts in research and control measures. Atmospheric pollution crossing international boundaries has become a concern in North America and Europe. The United States has signed the Convention on Long-Range Transboundary Air Pollution in the United Nations Economic Commission for Europe. Considerable further research on the direct effects of atmospheric pollution on human health and the environment is required if we are to make informed policy decisions. Current trends suggest that each problem will worsen as increasing amounts of coal are used for generating electricity.

Increasing concentrations of carbon dioxide (CO_2) resulting from all forms of fossil fuel combustion, and perhaps also from deforestation, are creating conditions that many scientists believe could raise the average temperature of the atmosphere and radically change global weather patterns. Additional research and monitoring are needed. During the next 10 years we should be able to clarify the impacts of the increasing transition of the United States and other nations to coal, oil shale, and synthetic fuels from coal for their energy needs. Increased CO_2 concentration may become one of the most controversial environmental problems of the next decade.

The stratospheric ozone layer protecting Earth's surface from damaging ultraviolet light is being affected by the emission of chlorofluorocarbons (CFC) from such sources as aerosol cans and refrigeration equipment, by nitrous oxide emissions from automobiles, and, possibly, by high-altitude aircraft flights. This is a subject of international concern, since the causes appear to stem from industrialized countries located all through the world. The most widely discussed potential effect of an increase in ultraviolet light penetration through the atmosphere is a higher incidence of skin cancer, but damage to food crops might prove to be the most serious ozone-related problem. Additional research is needed on the actual effects of emissions from social and industrial sources and on the effects of ozone depletion on vegetation.

MARINE POLLUTION

Over 90 percent of the pollution of the marine environment arises from land-based sources that enter the oceans from rivers, coastal outfalls, agricultural and urban runoff, and by transport through the atmosphere. Estuaries, marshes, swamps, and shallow coastal waters are habitats for many species of commercial fish, shellfish, and wildlife. They are also important areas for tourism, urban development, and human water supplies. Industrial chemicals, heavy metals, nuclear wastes and heat, pesticides and other agricultural chemicals, soil erosion, and sewage can all have deleterious impacts on human health and contribute to the contamination of what has been called the most biologically productive system on Earth.

The oceans, particularly areas near shore, have always been considered suitable places for waste disposal. As long as the ecosystem is not overloaded, dilution, degradation, and distribution can legitimately assist in waste disposal. However, as industrialization proceeds, increasing amounts of materials and pollutants find their way to marine areas, and overloads result. Pollution control costs are high, involving not only expensive equipment, but also decisions on such matters as factory siting, urban development, and land use. Many countries border on large bodies of water, and concerted action is necessary. Economic and political questions are being raised about shared resources, sovereign rights, availability of alternative waste disposal sites, and differing cultural values. The deliberate dumping of wastes directly into the oceans is a multifaceted and critical issue, with wide-ranging economic and ecological consequences. Research must identify the volume of material that can be tolerated without significant contamination of the food chains of water, and, ultimately, danger to human health.

The international aspects of marine pollution have become increasingly visible during the past decade because of oil spills. The *Torrey Canyon* oil spill in 1967, the more recent *Amoco Cadiz* and *Argo Merchant* spills, and the Campeche oil spill off the coast of Mexico called public attention to this environmental menace. The Law of the Sea Conference and a recent protocol to the Intergovernmental Maritime Consultative Organization (IMCO) Marine Pollution Convention prescribe effective international regimes to control marine pollution from vessels, but additional controls are needed. Although vessels account for only 10 percent of ocean pollution, larger tankers in international commerce will probably increase that figure, requiring international action to protect the ecology of the oceans.

WASTE MANAGEMENT

The United States is a major consumer of nature's bounty. Other countries urge us to be more conservative in our use of resources, and many see low-waste technology as a necessary development. Increased attention is expected to be paid to cooperative efforts in such technology. At present, there are unavoidable wastes that are not recyclable for technical or economic reasons. Such wastes must be disposed of in a way that does not threaten human life or the environment. As waste materials continue to accumulate, the pressures to solve the problem by exporting them for disposal abroad will increase.

Export of hazardous wastes is a difficult issue, as most countries do not have environmentally sound disposal or recycling capabilities. The United States has established a system for notifying potential importing countries of the nature of wastes, allowing those countries to prepare for disposal or recycling of the hazardous wastes in an environmentally acceptable manner.

MEDICINE AND HEALTH

Such illnesses as malnutrition and tropical diseases take a major toll in developing nations. The results are not only death and human suffering, but stagnation of economic progress due to the inability of the sick to contribute to society. The immediate need in most developing countries is for primary health care programs that can ensure better distribution of health services to all social and geographical groups. Safe drinking water and sanitation systems, better distribution of more nutritious food, stabilization of population growth, and general education could substantially improve health.

It is U.S. policy to promote greater attention to primary health care, the inclusion of health in the overall development framework, and self-reliance in health among developing nations. U.S. policy through AID and through the World Health Organization and other programs of the United Nations emphasizes primary health care along with safe drinking water, better nutrition, control of disease, effective health care delivery systems, and improved health planning. It is also U.S. policy to make available the Nation's vast expertise on medical and health issues and to work toward improvements in diagnosis, control, and treatment as well as prevention of disease.

INFORMATION, TELECOMMUNICATIONS, AND ADVANCED TECHNOLOGY

FREE FLOW OF INFORMATION

The principle of free flow of information and ideas regardless of national frontiers is fundamental to American culture and society. Some countries continue to urge international regimes under which controls over the flow or even the content of transborder communications would be acceptable. A number have adopted regulatory schemes for dealing with the flow of data that might affect the privacy or other rights of citizens. International efforts to protect rights and at the same time preserve freedom of information flow will become increasingly important in the next 5 years.

Growing Third World support for the concept of a New World Information Order is troublesome. The concept urges a "balanced" flow of information through controls on newsmen, an international "right of reply" to critical or unflattering news coverage, concessional communications tariffs, and the transfer of scientific and technical information to developing countries on concessional terms. The principal forum for promoting the concept has been UNESCO.

Our developed trading partners view the preponderance of the United States in information and data processing with some misgiving. They see an international economy dominated by an information-rich United States. Thus, the development of information and privacy policies in some countries has not been free of protectionist considerations.

In addition, the amount of capital needed to help bring the Third World up to a rough "balance" with the developed countries in communications is very great. The international community needs to mobilize bilateral, multilateral, and private sector assistance for communications development and to ensure that communications receives appropriate priority in national and international development strategies.

TELECOMMUNICATIONS

Rapid advances are being made in telecommunications technologies. Large-scale integration of electronic components is permitting equipment economies and promises to spawn new capabilities. A number of other technical advances indicate that the ease with which we communicate will grow both domestically and internationally, while the costs will diminish. We can anticipate rapidly increasing use of the radio frequency spectrum and of satellite geostationary orbit space by both developed and developing countries.

Because television is so effective a medium for the communication of ideas, many countries fear uncontrolled broadcasting from stations outside their jurisdictions. The broadcast of television from satellites to home receivers in other countries is of concern to many countries, and efforts are under way in the United Nations to deal with the problem. Developing countries are concerned that they will be preempted from the future use of satellites to meet their telecommunications requirements. They believe that the existing and planned space systems of industrialized countries will use all the available frequency and orbit resources. The crowding of the radio spectrum and of geostationary orbit space is increasing Third World demands for equitable sharing of that "common resource" of mankind.

Some advocate detailed advanced planning of space services that will guarantee availability of frequencies and orbit locations for developing countries in the future. In the next 5 years we expect to see several countries progress toward establishing domestic satellite television broadcasting systems, and at least one regional system may be started. That will probably raise the level of interest of a number of countries heretofore rather unconcerned about the issue. The existing international regulations for the use of the frequency spectrum and geostationary orbit space provide for satellite systems on an as-needed basis, and they ensure access to new systems implemented later. The United States will seek to retain the basic principles of those regulations in the belief that they result in more efficient use of the limited resources and will therefore serve all countries better in the long run.

CIVIL SPACE ACTIVITIES

We are witnessing a maturing of foreign space capabilities and a widespread international recognition of the benefits of space activity. National budgets and industry investments are increasing. Many countries now consider space significant enough to require more than an ad hoc approach to funding and policymaking. Space activities have become the subject of 5-, 10-, or 15-year plans in Japan, Italy, France, and India. Several other countries, among them Germany, Canada, and the Netherlands, are moving toward such long-range plans.

The United Nations Committee on the Peaceful Uses of Outer Space plays a major role in international space relations. The issues before the Outer Space Committee include the use of satellites for direct television broadcasting, remote sensing of Earth, use of geostationary orbit space, nuclear power sources in outer space, and the definition or delineation of outer space. The 1982 United Nations Conference on the Exploration and Peaceful Uses of Outer Space (UNISPACE '82) could become the focus of significant activity in 1981 and 1982. The working theme of the conference is application of space science and technology to the problems of developing countries. This could provide the opportunity to review and display the contributions and capabilities of U.S. Government and industry to help solve those problems.

The U.S. Space Shuttle will have a major impact on all areas of our international space relations during the next decade. The European Space Agency (ESA) has made a large investment in designing the first two Spacelabs to be launched by the Shuttle. Canada is developing the remote manipulator system, and a Swiss astronomer and a Dutch physicist will be trained by the National Aeronautics and Space Administration (NASA) as mission specialist candidates for the Shuttle.

International participation in the U.S. Landsat program also continues to grow. In 1980, stations began operation in Japan, India, Australia, Argentina, and South Africa—joining existing stations in Canada, Brazil, Italy, and Sweden. Landsat ground station agreements were signed with Thailand and China, and a number of other countries are considering joining the system. The European Space Agency, France, India, Japan, and the Soviet Union have also initiated remote sensing programs. The foreign programs offer the prospect of both competition and cooperation with the U.S. program. The high costs of remote sensing for all operators require avoidance of duplication in spacecraft and ground systems. It can be achieved by ensuring compatibility in future system developments and by taking advantage of complementarity of the various systems being planned.

Careful management of data dissemination and pricing in the U.S. program is needed to increase international cooperation and participation. Many international users rely heavily on Landsat data, not only for resource applications, but for education and research. Regional meetings with developing countries to incorporate their needs into plans for future systems are scheduled for 1981 and 1982.

A joint study of ultrahigh frequency mobile satellite communications is under way with Canada. The possibilities of a joint mission, configuration for the satellite, a ground network, and sharing arrangements for hardware development have been examined. The United States, Canada, and France have agreed to evaluate a Satellite-Aided Search and Rescue Communications System, designated SARSAT. They have concluded an understanding with the Soviet Union for cooperation between SARSAT and a similar Soviet system called COSPAS. Under the terms of the understanding, the two systems will be interoperable. Norway has asked to join the SARSAT experiment and has been approved in principle as an investigator. Sweden, Italy, Japan, and Brazil are considering joining the Western nations, and Bulgaria, the German Democratic Republic, and Poland may join the Soviet segment. The system will use both Soviet and U.S. satellites.

As part of our effort to understand the nature of the Sun and its effects on Earth, NASA launched the Solar Maximum Mission Satellite in February 1980. Scientific instruments for the mission were contributed by the United Kingdom and the Netherlands.

The importance to the United States of all this international cooperation is immeasurable. Not only does it help us to cut costs by sharing responsibilities and benefiting from the technology of others, but it allows us to remain a leader in space activity. In an era of inflation, and increasing competition in space, it is important that the United States find a way to remain competitive in the "space race." There are many who depend upon our ability to do so.

APPENDICES

Bibliography

A selected bibliography has been prepared to assist readers in locating additional information on topics covered in the *Five-Year Outlook*. The items in the bibliography are arranged alphabetically by author within the 13 broad categories of the *Outlook*:

- Maintenance and Development of the Science and Technology Base,
- Contributions of Science and Technology to Industrial Innovation, Productivity, and Economic Growth,
- The International Context of U.S. Science and Technology,
- Science, Technology, and Policymaking,
- National Security,
- Space,
- Health,
- Energy,
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- Environment,
- Transportation,
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- Education.

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Index

A

- **Abt Associates, 550**
- **Accidents, 68, 300, 342–344, 345, 444, 445, 446, 779, 780, 805**
- **Acid rain, xxv, 131–132, 742, 756, 769, 771, 783, 800**
- **Acts of Congress**
  - *See Congressional Acts*
- **Adirondacks**
  - Acid rain, **132**
- **Administrative records, 611–613, 662–664**
- **Advanced Operational Meteorological System, 724**
- **Afghanistan invasion, 468, 471, 526**
- **Africa**
  - Age-set societies, **625**
  - Agricultural production, **478, 499, 507**
  - Bilateral agreements with U.S., **485**
  - Demographic features, **5, 6, 8, 10, 12, 13, 505**
  - Game parks, **479**
  - Mineral resources, **366, 519, 765**
  - *See also specific countries*
- **Age factors**
  - Health care behavior, **575–576**
  - Intelligence, **633–637**
  - Mortality, **444**
  - Social attitudes, **656–657**
  - *See also Lifespan perspective*
- **Age structure of population, xxix, 7, 9, 506, 508, 642–643, 801**
- **Agency for International Development (AID), 466, 486, 487, 495, 550, 762, 801, 802, 806**
- **Aggression**
  - Child development, **676–680**
  - War, **523–531**
- **Aging, 68–70, 621–648**
- **Agrichemicals, 114, 116, 118, 130, 207, 292, 448, 449, 771–772, 785**
- **Agriculture, 466–467, 477–478, 491–502, 781–789**
  - Climate effects, **21, 115, 119–120, 478, 479, 491, 497–498, 783**
  - Developing countries, **xxix, 15, 477–478, 480, 507, 786–787, 801**
  - Energy concerns, **16, 116**
  - Environmental concerns, **130–131, 493–494, 499, 782**
  - International research cooperation, **466–467, 480, 484, 486, 496, 498–500, 801**
  - Productivity, **16, 492–494, 496–498, 782–785**
  - Water concerns, **21, 125, 130–131, 493, 783**
  - *See also Biomass*
  - *See also Plants*
- **Agriculture, Department of (USDA), 467, 486, 494, 495, 496, 498, 550, 763, 764, 769, 773, 782, 785, 792, 797, 801, 802**
  - *See also specific parts*
- **AgRISTARS, 723**
- **Air Force, Department of the, 708, 709, 710, 711, 712, 719**
- **Air pollution, 771**
  - Energy production and use, 324–325, 742–743
  - Global concerns, **468–469, 480, 804–805**
  - Indoor, **141, 302, 455, 770**
  - Transportation, **299, 344–345, 771**
  - *See also Acid rain*
  - *See also Greenhouse effect*
- **Aircraft/air transportation**
  - Capacity issues, **333–334, 348**
  - Defense, **297, 707, 708–709, 711**
  - Energy/materials, **296–297, 338–339, 340, 341, 708–709, 711, 712, 713, 749, 777**
  - Pollution, **344–346**
  - Safety, **343, 780**
- **Aircraft industry, 296–298, 304, 346, 347, 778–779**
- **Alabama**
  - Redstone Arsenal, **711**
- **Alaska**
  - Oil and gas resources, 739
  - Pipeline, **180**
- **Alcohol abuse, 41, 731, 732, 733**
- **Alcohol, Drug Abuse and Mental Health Administration (ADAMHA), 728, 731–733, 734**
- **Aluminum resources, 17, 364, 518, 519, 712, 713**
- **American Enterprise Institute, 550**
- **American Industrial Health Council, 453, 454**
- **American Physical Society, 454–455**
- **American Society for Microbiology, 436**
- **Ampex, 411, 412, 413, 414**
- **Animal experimentation, 37, 38, 42, 54, 126, 572, 732**
  - Extrapolation between species, **xxvii, 126, 295, 593, 716**
- **Animals (farm)**
  - *See Livestock productivity*
- **Antarctic, 161, 804**
- **Antarctic Treaty, 804**

Page numbers i–385 are in the first *Source Volume;* page numbers 387–807 are in the second *Source Volume.*

- **Antitrust policy, xxviii, 463, 788**
- **Apollo missions, 159, 722**
- **Appropriate technology, 465, 477, 486, 789, 801**
- **Appropriate Technology International, 486, 801**
- **Aquaculture, 766, 785**
- **Aquatic ecology, 99–100, 108, 132–134, 138**
- **Arctic, 764, 804**
- **Argentina**
  - Landsat stations, 764, 807
  - Pronatalist policies, 9
- **Argonne National Laboratory, 332, 357, 751**
- **Arid lands**
  - Management, 763–764, 803
  - Waste disposal, 129, 148
- **Arizona**
  - Kalamazoo copper deposit, 368
  - Tucson water conservation, 136
- **Arkansas**
  - Weed control, 118
- **Arms control, 470, 527**
- **Army, Department of the, 448, 708, 710, 763**
- **ARPANET, 708**
- **Arthritis, 51–56**
- **Artificial intelligence, 89–91, 371–374, 706–707, 714, 755, 794**
- **Asbestos, 41, 364, 403, 573**
- **Asia**
  - Agricultural production, 497, 499
  - Demographic features, 8, 9, 10, 12, 505
  - *See also specific countries*
- **Asilomar conference, 402, 431, 432**
- **Astronomy**
  - *See Space science*
- **AT&T—427**
- **Atherosclerosis**
  - *See Cardiovascular disorders*
- **Atlantic Coast**
  - Blake Plateau manganese nodules, 765
  - Ecosystems research, 101
- **Atmospheres, 172–177, 180, 721, 724, 755**
- **Atmospheric Explorer satellites, 176**
- **Atomic Energy Act of 1954, 140**
- **ATS-6 (satellite), 179**
- **Australia**
  - Bauxite resources, 518
  - Cancer, 40
  - Cardiovascular disorders, 729
  - Crop control, 114, 118
  - Demographic features, 9
  - Energy resources, 311, 741
  - Landsat stations, 764, 807
  - Radioactive waste management, 150
  - Uranium, 365, 468
  - U.S. mineral imports from, 364
- **Austria**
  - Demographic features, 3, 9, 19
- **Automobiles/automobile transportation**
  - Energy/materials, 290, 299–300, 338, 339–340, 342, 347–348, 359, 749–750, 777–778
  - Pollution, 299, 344, 346, 452, 454
  - Safety, 300, 343, 446, 779
  - *See also Highway transportation*
- **Automobile industry, xxvi, xxviii, 298–300, 303, 304, 346, 347, 463, 519**
- **Automotive Engineers, Society of, 346**
- **Avco, 412**
- **Aviation**
  - *See Aircraft*

B

- **Baja California**
  - Hot Springs, 365
- **Bangladesh**
  - Demographic features, 4, 10, 12, 20, 503, 509, 510
  - GNP growth, 507
  - Jute exports, 484
- **BART (Bay Area Rapid Transit), 340**
- **Batavia Stanford, 256**
- **Battelle Pacific Northwest Laboratories, 150**
- **Batteries, 222, 342, 360, 362, 712, 747, 750**
- **Bauxite resources, 17, 518, 519**
- **Behavior**
  - Aggression, 523–531, 676–680
  - Animals, 103–105
  - Health relationship, 29–30, 35, 40–41, 51, 546, 561–588, 729, 731–732
  - Human development, 546, 553–554, 623–625, 669–695
  - Lifespan perspective, 546, 621–648
- **Behavior modification, 555, 579–581, 583–585**
- **Behavioral Sciences, Center for Advanced Study in the, 549**
- **Belgium**
  - Demographic features, 9
  - Productivity growth, 408
- **Beryllium resources, 712**
- **Biofeedback, 581**
- **Biogen, 430**
- **Biological warfare, 715–716**
- **Biomass, 310, 311, 313, 322–323, 325, 748, 751, 789**
- **Biomaterials, 55, 56, 352**
- **Biosafety committees, 433**
- **BLITECAST, 116**
- **Board on . . .**
  - *See other part of name*
- **Bolivia**
  - U.S. mineral imports from, 364
- **Brazil**
  - Airplane manufacture, 778
  - Bauxite resources, 518
  - Demographic features, 4, 10, 11–12, 506
  - Ethanol use, 476, 478
  - Government/society relationship, 548
  - Landsat stations, 764, 807
  - Natural radiation, 141
  - Nuclear power development, 478
  - Oil shale resources, 311, 320
  - Soybean production, 788
  - Space/satellite programs, 725, 807
  - Thorium deposit, 144
  - U.S. mineral imports from, 364
- **Brookhaven National Laboratory, 256, 358, 359, 751**
- **Brookings Institution, 550**
- **Brown, Congressman George, xxi**
- **Bulgaria**
  - Demographic features, 9
  - Satellite systems, 807
- **Bureau of . . .**
  - *See other part of name*
- **Burma**
  - Demographic features, 4, 10, 20
- **Bus transportation, 338, 340, 347, 777, 778**

C

- **Calculators, 792**
- **California**
  - Barstow solar plant, 301, 747
  - Berkeley Biodynamics Laboratory, 278
  - Berkeley Growth Study, 686
  - Diesel regulations, 344
  - Frost-sensitive plants, 120
  - San Francisco BART system, 340
  - San Francisco Bay Area child development studies, 640
  - Seismic hazard, 455, 764, 765
  - Stanford Five Cities program, 585
  - Stanford Heart Disease Prevention Project, 580
  - Weed control, 101
- **Canada**
  - Acid rain, 132, 742
  - Airplane manufacture, 778
  - Cardiovascular disorders, 729
  - Copper resources, 518
  - Defense tracking system, 705
  - Demographic features, 8, 9
  - Energy resources, 740
  - Landsat stations, 764, 807
  - Plant disease, 111, 112, 114, 118
  - Productivity growth, 408
  - Radio frequency noise standards, 346
  - Radioactive waste management, 146, 151
  - Space/satellite programs, 725, 807
  - Uranium, 365, 468
  - U.S. mineral imports from, 363–364
  - Water quality concerns, 802
- **Cancers, xxvii, 18, 35–46, 72, 126, 142, 144, 351, 352, 573–574, 730**
  - *See also Carcinogens*
- **Carbon dioxide**
  - *See Greenhouse effect*
- **Carcinogens, 37–43, 126, 137, 295, 344, 447, 449, 450, 453, 730, 731, 770**
- **Cardiovascular disorders, 6–7, 28–35, 62, 444, 446, 562, 563, 564–571, 580, 583, 584–585, 729–730**
- **Carnegie Institute of Washington, 278**
- **Cartels, 517, 518, 519**
- **Carter, Jimmy (Administration), 140, 286, 418, 453, 463, 604, 654**
- **Census (U.S.), 595, 598, 599, 654**
- **Census, Bureau of the, 595, 599, 605, 606**
  - *See also Current Population Survey*
- **Center for . . .**
  - *See other part of name*
- **CERN**
  - *See European Organization for Nuclear Research*
- **Chemical carcinogens**
  - *See Carcinogens*
- **Chemical industry, xxiii, 286, 290–293, 304, 403, 731**
- **Chemical Industry Institute of Toxicology, 454**
- **Chemistry, xxii, xxiii, 183–229, 751, 757**
- **Children**
  - Development, 546, 553–554, 624, 625–626, 669–695
  - Mortality, 6, 7, 510
- **Chile**
  - Copper resources, 518
  - Liquefied natural gas resources, 741
  - U.S. mineral imports from, 364
- **China, Committee for Scholarly Communication With the People's Republic of (CSCPRC), 551**
- **China, People's Republic of**
  - Agricultural production, 497, 499, 500
  - Bilateral agreements with U.S., 485, 551
  - Cancer, 38
  - Coal resources, 311
  - Demographic features, 5, 10–11, 13, 14, 503, 506, 509, 510
  - Earthquake prediction, 764
  - Health care delivery, 476
  - Landsat stations, 764, 807
  - Space programs, 725
- **Chinese-American community, 14, 38**
- **Chromium resources, 364, 366, 518, 519, 712, 765**
- **Cigarette smoking, 7, 40–41, 445, 562, 563, 573, 578–580, 584, 656–657, 732–733**
- **Cities**
  - *See Urban areas*
- **Citizen . . .**
  - *See Public . . .*

Page numbers i–385 are in the first *Source Volume;* page numbers 387–807 are in the second *Source Volume.*

- **Clean Air Act (1970), 344, 447, 448, 452, 749**
- **Clean Water Act (1977), 130, 132**
- **CLIMAP, 161**
- **Climate and weather**
  - Agriculture relationship, 21, 115, 119–120, 478, 479, 491, 497–498, 783
  - Defense concerns, 711
  - International research cooperation, 177, 479, 486, 803–804
  - National Climate Program, 773, 803
  - Prediction, 723, 724
  - Sun-climate connections, 160–162, 165, 166, 180–181
  - Weather modification, 803
  - *See also Greenhouse effect*
- **Clinch River Breeder Reactor Plant, 744**
- **Cloning, 754**
  - *See also Recombinant DNA*
- **Coal**
  - Environmental concerns, xxv, 16, 324–325, 446, 742–743
  - Processing, 302, 303, 312–319, 321, 322, 323, 326, 327–328, 329, 366, 464, 740, 741–742
  - Supply and demand, 309, 310, 311, 736, 737, 739
  - Transportation, 332, 337, 746
- **Cobalt resources, 17, 364, 517–518, 519, 520, 712, 765**
- **COCORP (Consortium for Continental Reflection Profiling), 368**
- **Coding/encryption systems, 242, 708**
- **Cognitive science, 75–92, 674–676, 755, 793–794**
- **Collaborative Research Support Programs (CRSPs), 486, 498, 499**
- **Colombia**
  - Cancer, 40
  - Demographic features, 503
  - Liquefied natural gas resources, 741
  - Rice production, 500
- **Colorado**
  - Denver natural radiation, 141
  - Henderson molybdenum deposit, 368
  - Oil shale resources, 319, 324, 329
  - Piceance Basin gas resources, 741
- **Colorado River, 125, 130, 802**
- **Commerce, Department of, 763, 782, 802**
  - *See also specific parts*
- **Commission on . . .**
  - *See other part of name*
- **Committee on . . .**
  - *See other part of name*
- **Communicable Disease Center, 486**
- **Communications equipment/technologies, 288, 289–290, 422, 793**
  - Aircraft, 725, 780
  - Defense, 707–708
  - International issues, 426, 469, 484, 806
  - Networks, 422, 707–708, 724
  - Ships, 345, 348, 708, 725, 780
  - Societal impacts, 401, 404, 508
  - *See also Information . . .*
  - *See also Satellites*
- **Communications industry, 290, 401, 422, 424–425, 427–428**
- **Computer applications**
  - Aircraft, 297, 707, 780
  - Automobiles, 299, 300, 333
  - CAD/CAM,419, 707, 779
  - Chemistry, 90, 215, 219–220, 226, 328, 714
  - Defense, 706–708, 713–714, 716
  - Drug industry, 215, 295
  - Educational research, 78, 79, 86, 89
  - Energy distribution, 746
  - Health care, 90, 350, 352, 714, 716, 734
  - Home, 423, 427, 792–793
  - Instruction/testing, 76, 220, 426, 713–714, 792–793, 794–795
  - Mathematics, 232, 242, 243, 251, 714
  - Office, 90, 422, 423, 427, 794
  - Plant pathology, 116
  - Port facilities, 336, 348
  - Space vehicles, 369, 719
  - Survey techniques, 589, 595, 596–597, 599
  - Traffic control, 780
  - Weather prediction, 803
  - *See also Artificial intelligence*
  - *See also Robots*
- **Computer science, 234–237, 251, 371, 373–374**
- **Computer software (programming), 289, 372, 706**
- **Computers, 421–422, 426–427, 792**
  - *See also Electronic components*
  - *See also Man-machine interface*
- **Conflict studies, 470, 526–527**
- **Congress, 129, 431, 433, 436, 437, 452, 470, 487, 496, 498–499, 794**
- **Congressional Acts**
  - Atomic Energy Act of 1954, 140
  - Clean Air Act (1970), 344, 447, 448, 452, 749
  - Clean Water Act (1977), 130, 132
  - Consumer Product Safety Act, 452
  - Deep Seabed Hard Mineral Resources Act, 765
  - Delaney Amendment, xxvii, 42, 447
  - Elementary and Secondary Education Act, 76
  - Endangered Species Act, 96
  - Energy Policy and Conservation Act of 1975, 339, 344
  - Energy Reorganization Act of 1974, 140
  - Energy Security Act of 1980, 311, 329
  - Energy Tax Act of 1978, 750
  - Federal Environmental Pesticide Act, 452
  - Federal Water Pollution Control Act, 130, 134, 135, 452
  - Fire Prevention and Control Act, 452
  - Fishery Conservation and Management Act of 1976 (FCMA), 765–766
  - Food, Drug and Cosmetic Act, xxvii, 295, 452
  - Freedom of Information Act, 663
  - Immigration Acts, 13, 14
  - Mansfield Amendment of 1969, 400
  - Merchant Marine Act of 1936, 1970 Amendments, 334
  - Mine Safety and Health Act, 452
  - Morrill Act of 1863, 255
  - Motor Carrier Act of 1935, 336
  - National Aeronautics and Space Act of 1958, 718
  - National Defense Education Act of 1958, 550
  - National Earthquake Hazards Reduction Act, 452
  - National Energy Conservation Policy Act, 302
  - National Environmental Protection Act, 96, 133, 140
  - National Gas Policy Act of 1978, 747
  - National Materials and Minerals Policy, Research and Development Act of 1980, 765
  - National Science and Technology Policy, Organization and Priorities Act of 1976, i, xvii, 389
  - Noise Control Act, 452
  - Occupational Safety and Health Act, 452
  - Patent Act of 1790, 436
  - Plant Patent Act of 1930, 436
  - Plant Variety Protection Act of 1970, 436
  - Resource Conservation and Recovery Act, 452
  - Safe Drinking Water Act of 1974, 126, 448, 452, 763, 773
  - Stevenson-Wydler Technology Innovation Act of 1980, 408
  - Tax Reform Act of 1976, 612
  - Toxic Substances Control Act of 1976, 42, 132–133, 448, 450, 452, 769
  - Water Research and Development Act of 1978, 763
- **Congressional Research Service (CRS), 452**
- **Consultative Group on International Agricultural Research (CGIAR), 480, 486, 498, 499, 500, 801**
- **Consumer electronics industry, 399, 407, 409–416**
- **Consumer Price Index, 595**
- **Consumer Product Safety Act, 452**
- **Consumer Product Safety Commission, 402, 450, 452, 731**
- **Contraception**
  - *See Family planning*
- **Convention on Long-Range Transboundary Air Pollution, 804**
- **Convention on the Conservation of Antarctic Marine Living Resources, 804**
- **Cooperative Automotive Research Program (CARP), 463**
- **Copper resources, 17, 364, 365, 366, 518, 519, 520, 804**
- **Copyright, 427**
- **Cost/benefit analysis, 446, 448–449, 453, 768**
  - *See also Risk/benefit analysis*
- **Cotton Development International (CDI), 484**
- **Council . . .**
  - *See other part of name*
- **Court actions**
  - Patenting of living organisms, 435–436, 438
  - Risk assessment, 453
- **Crime/prisons, 654–656, 671–672**
- **Crop productivity, 492–494, 496–497, 783–784**
  - *See also Plants*
- **Cuba**
  - Crop losses, 114
  - Cuban crisis, 525, 527
  - Demographic features, 6
- **Cultural factors, 415–416, 547–548, 564, 576, 625, 628, 673**
- **Current Population Survey, 591, 592, 593, 596, 599, 603, 605, 606, 611, 612**
- **Cyprus**
  - Copper ores, 366
- **Czechoslovakia**
  - Demographic features, 9

D

- **Data bases, 425, 427**
  - Health/chemistry, 35, 219–220, 731, 734
  - Statistical (government records), 554, 611–613, 662–664
- **Data processing**
  - *See Computers*
  - *See Information*
- **Decisionmaking (human), 88–89, 90–91, 92, 714–715**
- **Deep Seabed Hard Mineral Resources Act, 765**
- **Defense, 469–471, 523–531, 703–716**
  - Aeronautical technologies, 297, 707, 708–709, 711
  - Communication technologies, 707–708
  - Electronics/computer technologies, 704–707
  - Health concerns, 715–716
  - Manpower, 713–715
  - Materials technologies, 711–713
  - Nuclear test verification, 710
  - Philosophy/theories, 469–470, 523–531, 547
  - R&D support (Europe), 258, 263, 269, 274, 279
  - R&D support (U.S.), 258, 279, 400, 471, 704
  - R&D support (U.S.S.R.), 704
  - Radioactive wastes, 145–146, 153
  - Science and technology effects on, 469–471, 523–531
  - Space defense, 709
  - U.S. leadership in, 704
  - Weapons systems, 710–711

Page numbers i–385 are in the first *Source Volume*; page numbers 387–807 are in the second *Source Volume*.

- **Defense Advanced Research Projects Agency (DARPA), 275, 708, 709, 710, 711, 712**
- **Defense Communication Agency (DCA), 708**
- **Defense, Department of, 298, 320, 342, 530, 703–716, 718, 792, 796, 797**
  - *See also specific parts*
- **Deforestation**
  - *See Forest resources*
- **Delaney Amendment, xxvii, 42, 447**
- **Delaware River Basin Commission, 134**
- **Democratic Republic of Germany**
  - *See Germany, Democratic Republic of*
- **Demography, xxviii–xxix, 3–25, 503–511, 554**
  - *See also Age structure of population*
  - *See also specific demographic variables*
- **Denmark**
  - Cancer, 40
  - Cardiovascular disorders, 729
  - Demographic features, 9
- **Dental research, 733**
- **Department of . . .**
  - *See other part of name*
- **Desertification**
  - *See Arid lands*
- **Developing countries, 464–467, 475–490**
  - Agriculture and food, xxix, 15, 477–478, 480, 507, 786–787, 801
  - Competition with, 482, 483
  - Demographic features, xxix, 4, 5–6, 8, 10–12, 14, 18, 23, 479, 480, 491, 503–506, 508, 509–510, 800–801
  - Ecological concerns, 478–479, 480
  - Economic development/labor, 479, 508, 518–519, 801
  - Energy, 477, 478
  - Environmental concern, 480
  - Foreign assistance, xxviii, 22, 465–466, 477, 485–486
  - Geophysical research, 479
  - Health care, 476, 477, 805, 806
  - Information/communications, 469, 483–484, 758, 806
  - Remote sensing, 486, 807
  - Resources/raw materials, 484, 518–519, 765
  - Science and technology infrastructure, 465–466, 480–482, 801–802
  - Technology policy toward, 465–466, 483
  - *See also International research cooperation*
  - *See also specific countries*
- **Devonian shale, 310, 319, 739, 741**
- **Diabetes, 30, 46–51, 733**
- **Disarmament, 470, 527**
- **Disease**
  - *See Health and medicine*
  - *See specific disorders*
- **Disease Control, Centers for (CDC), 731, 734**
- **Divorce**
  - *See Family characteristics*
- **DNA, 37, 39, 103, 117, 190–191, 353–354, 754**
  - *See also Recombinant DNA*
- **Domestic Policy Review**
  - Industrial Innovation, 418
- **Drinking water, 125–127, 137, 763, 772–773**
- **Drug abuse, 731, 733**
- **Drug synthesis, 50, 211, 213–215, 226, 293–295, 352, 355, 375, 432, 728, 730**
  - *See also Pharmaceutical industry*
- **duPont, 418**

E

- **Earth Day, 1970, 402**
- **Eastern Europe**
  - *See Europe*
- **Ecology**
  - *See Ecosystems research*
- **Economic Advisers, Council of**
  - 1981 report, 398, 400
- **Ecosystems research, xxiii, 95–109, 132–134, 136, 138, 478–479, 480**
- **Ecuador**
  - Demographic features, 70
- **Education, 713–714, 791–798**
  - Cognitive science, 75–92, 674–676, 755, 793–794
  - Employment relationship, 630, 632–633, 643
  - *See also Education (Curricula)*
  - *See also Universities*
- **Education (Curricula), 792**
  - Adult education, 643
  - Business education, 400, 418, 419
  - Defense training, 714
  - Mathematics, 243, 797
  - Polymer science, 205
  - Science and engineering, xxiv–xxv, 426, 795–798
  - *See also Universities*
- **Education, Department of (ED), 792, 795**
  - *See also specific parts*
- **Educational Research and Improvement, Office of (OERI), 792**
- **Egypt**
  - Demographic features, 4, 8, 10, 503
- **Elderly, xxix, 7–8, 9, 628, 642, 733, 789**
  - *See also Aging*
- **Electric power generation, 303, 311, 357, 358–359, 360–362, 746**
- **Electric Power Research Institute, 301, 320, 358, 454**
- **Electric vehicles, 342, 347–348, 359, 750, 777–778, 780**
- **Electronic components, 221–222, 226, 288–290, 297, 355–359, 704–706, 757, 758**
  - *See also Communications technologies*
  - *See also Computers*
  - *See also Consumer electronics industry*
  - *See also Information technologies*
- **Electronic mail systems, 427**
- **Electronic publishing, 427**
- **Electronic warfare, 705–706**
- **Elementary and Secondary Education Act, 76**
- **Emigration**
  - *See Migration*
- **Employment**
  - Demographics relationship, 9, 10, 508, 642–643
  - Education relationship, 630, 632–633, 643
  - Lifespan perspective, 627, 628, 629–633, 642–643
  - Measurement, 556, 653–654
  - Scientists and engineers, xxv, 257, 281, 283, 601–602
  - Women, 633, 687–688
- **Endangered species, 478–479, 488**
- **Endangered Species Act, 96**
- **Energy, 17, 300–304, 309–330, 374, 735–752**
  - Agricultural concerns, 16, 116
  - Conservation, 291, 302, 337, 736, 749–750, 777
  - Developing countries, 477, 478
  - Environmental concerns, xxv, 16, 324–325, 446, 739, 742–743, 769
  - Foreign trade, 311, 332, 337
  - International cooperation, 303, 304, 464, 486–487, 802
  - Overview of options, xxv, 16, 301–302, 303–304, 309, 313, 329, 738
  - R&D funding, 300–301, 302, 738
  - Renewable sources, 747–749
  - Risk assessment comparison, 446, 447
  - Statistics gathering, 595, 603, 613, 650
  - Storage systems, 359–363, 746–747
  - Supply and demand, xxv, xxvi, 16, 301, 309–311, 513–522, 736–737
  - Supply interruptions, 467–468, 520–521
  - Transportation concerns, 296–297, 299, 301, 303, 304, 311, 337–342, 347–348, 736–737, 749–750, 777–778
  - Transportation of, 311, 326, 332, 337, 517, 746
  - Waste sources, 748–749
  - Water concerns, 125, 326
  - *See also specific forms of energy*
- **Energy, Department of (DOE), 140, 148, 300, 301, 320, 367, 447, 470, 486, 603, 735–752, 763, 769, 773, 782, 792, 796, 797, 804**
- **Energy Information Administration (EIA), 595**
- **Energy Mobilization Board, 302**
- **Energy Policy and Conservation Act of 1975, 339, 344**
- **Energy Reorganization Act of 1974, 140**
- **Energy Research Advisory Board (ERAB), 748**
- **Energy Security Act of 1980, 311, 329**
- **Energy Tax Act of 1978, 750**
- **Engineers**
  - *See Scientists and Engineers*
- **Engines (combustion equipment), 328, 339–342, 344, 346, 369, 708–709, 711, 713, 749, 771**
- **England**
  - *See Great Britain*
- **Environment, 767–773**
  - Agricultural concerns, 130–131, 493–494, 499, 782
  - Energy pollutants, xxv, 16, 324–325, 446, 739, 742–743, 769
  - Global concerns, 462, 467–469, 480, 804–805
  - Health concerns, 730–731
  - Regulations, 402–404, 464, 468
  - Transportation pollutants, 299, 344–346, 452, 454, 771
  - *See also specific topics*
  - *See also specific types of pollution*
- **Environmental impact statements, 133, 152**
- **Environmental Quality, Council on, 140**
- **Environmental Protection Agency (EPA), 126, 131, 133, 136, 140, 142, 144, 344, 346, 402, 433, 438, 448, 450, 452, 454, 728, 731, 763, 769, 782**
- **Equatorial Magnetosphere Laboratory (EML), 172**
- **Ethanol, 212, 312, 313, 322, 476, 478**
- **Ethics**
  - Data uses, 612
  - Drug testing, 295
  - Moral behavior development, 675, 676–680
  - Recombinant DNA research, 430, 436, 438–439
  - Science as a political threat, 526
- **Europe**
  - Aircraft industry, 298
  - Automobile industry, 346
  - Cardiovascular disorders, 729
  - Chemical industry, 291
  - Cognition research, 91
  - Demographic features, 3, 8–9, 12, 13, 505, 506, 510
  - Dependence on foreign oil, 468
  - Fusion magnet development, 358
  - Research and development, xx, 255–284
  - Robotry research, 90
  - Scholarly exchange program, 551
  - *See also specific countries*
- **European Economic Community, 298**
- **European Molecular Biology Organization, 262, 274, 279**
- **European Organization for Nuclear Research (CERN), 261, 263, 265, 269, 270, 274, 279, 303, 357–358**
- **European Science Foundation, 262**
- **European Space Agency (ESA), 172, 261, 720, 721, 725, 807**
- **European Space Sciences Organization, 274**
- **Evolution (natural selection), 103, 105–107, 108**
- **Explorer I, 177**
- **Exports**
  - *See Foreign trade*
- **Exxon, 319, 324, 419, 740**

Page numbers i–385 are in the first *Source Volume*; page numbers 387–807 are in the second *Source Volume*.

F

- **Family characteristics, 12, 19, 510, 627, 637–641, 651–652, 653, 659, 687–691, 732**
  - *See also related Socioeconomic factors*
- **Family planning, 8–9, 11, 12, 19, 467, 479, 485, 508, 509–510, 801**
- **Federal Aviation Administration (FAA) 333, 345**
- **Federal Communications Commission (FCC) 290, 425, 427**
- **Federal Emergency Management Agency (FEMA), 452**
- **Federal Energy Administration, 516**
- **Federal Environmental Pesticide Act, 452**
- **Federal Interagency Advisory Committee on Recombinant DNA Research, 433**
- **Federal Privacy Protection Commission, 425**
- **Federal Railroad Administration, 335–336**
- **Federal regulations**
  - *See Government regulations*
- **Federal Republic of Germany**
  - *See Germany, Federal Republic of*
- **Federal Trade Commission, 418**
- **Federal Water Pollution Control Act, 130, 134, 135, 452**
- **Federal Wildlife Service, 762**
- **Fermi National Laboratory, 358**
- **Fertility, 3, 8–12, 19, 22, 23, 105–106, 467, 503–504, 508, 509–510**
  - *See also Family planning*
- **Fiber optics**
  - *See Optical fibers*
- **Finishes industry, 292**
- **Finland**
  - Cardiovascular disorders, 31, 580, 729
  - Demographic features, **9**
- **Fire Prevention and Control Act, 452**
- **Fishery Conservation and Management Act of 1976 (FCMA), 765–766**
- **Fishery resources, 17, 99–100, 102, 723, 765–766, 804**
- ***Five-Year Outlook***
  - Preparation, i, **xvii, xxii, 389–391, 394, 701**
  - Purpose, **xvii, xix, 389, 393, 545, 553**
- **Florida**
  - Natural radiation, **141**
- **Fluorine imports, 364**
- **Food**
  - *See Agriculture*
  - *See Nutrition*
- **Food and Agriculture Organization (FAO), 507, 801, 804**
- **Food and Drug Administration (FDA), 295, 433, 447, 449, 450, 452, 467, 728, 731, 734**
- **Food, Drug and Cosmetic Act, xxvii, 295, 452**
  - *See also Delaney Amendment*
- **Food Safety Council, 453**
- **Ford Foundation, 550**
- **Foreign trade, xx, xxi, 285, 304, 400, 463–464, 472, 521, 777, 778**
  - Aircraft, **298, 304, 346, 778–779**
  - Automobiles, **304, 346, 475, 519, 778, 779**
  - Chemicals, **291, 304**
  - Drugs, **296, 485**
  - Electronics, **304, 399, 410, 411, 475**
  - Food, **15, 468, 477–478, 494, 783**
  - Foreign policy tool, **468, 471**
  - Fossil fuels, **310, 332, 337, 741, 777**
  - Hazardous substances/wastes, **484–485, 805**
  - Marine transportation, **334–335, 779**
  - Mass transit vehicles, **778**
  - Nonfuel minerals, **363, 364, 366, 518–519, 520, 765**
  - Steel, **519**
  - Technology, **xxi, 463, 465, 468, 471, 483**
  - Textiles, **519**
  - Uranium, **468**
  - U.S. trade balance, **287, 777**
- **Forest resources, 17, 96–97, 98, 480, 488, 500, 762–763, 800, 802**
  - *See also Wood*
- **Forest Service, 100, 762**
- **Fossil fuels, xxvi, 309–338, 739**
  - *See also specific fuels*
- **France**
  - Airplane manufacturing, **346, 778**
  - Demographic features, **3, 9, 14, 20**
  - Drug companies, **296**
  - Energy development, **303**
  - Neutron scattering experiments, **197**
  - Productivity growth, **286, 408**
  - Radioactive waste management, **150**
  - Seabed mining, **765**
  - Space/satellite programs, **725, 807**
  - *See also Research and development, France*
- **Freedom of Information Act, 663**
- **Fuel science, xxvi, 309–330, 738–742**
  - *See also specific fuels*
- **Fulbright Program, 551**

G

- **Gabon**
  - Natural fission reactor, **144**
  - U.S. mineral imports from, **364**
- **Galapagos Islands**
  - Ore deposits, **366**
- **Galileo project, 722**
- **Gamma Ray Observatory, 720**
- **Gas**
  - *See Natural gas*
- **Gas Research Institute, 301**
- **Gasoline, 301, 312, 317, 321, 777**
- **Gender differences**
  - *See Sex differences*
- **Genentech, 429**
- **General Accounting Office (GAO), 452, 455**
- **General Electric, 410, 414, 415, 416, 418**
- **Generators, 358, 709, 747**
- **Genetic defects of metabolism, 64–65**
- **Genetics Institute, 430**
- **Genetics research**
  - Humans, **53–54, 351–352, 353–354, 568–569, 570, 582–583, 732, 754**
  - Plants, **xxix, 103, 112–113, 116, 117–118, 120, 754, 784**
  - *See also DNA*
  - *See also Recombinant DNA*
  - *See also RNA*
- **Geological Survey, 468, 486, 516, 741, 763, 764**
- **Geology, xxiii, 364–366, 514–515, 518, 521, 755–756**
- **Geomagnetic Tail Laboratory (GTL), 172**
- **Georgia**
  - Shenandoah solar thermal project,**747**
- **Geostationary Orbit Environmental Satellite, 724**
- **Geosynchronous orbit, 179, 426, 719, 724, 806**
- **Geothermal energy, 748**
- **Germany, Democratic Republic of**
  - Demographic features, **9**
  - Satellite programs, **807**
- **Germany, Federal Republic of**
  - Aeronautical R & D, **346**
  - Cardiovascular disorders, **729**
  - Coal development, **303, 312–313, 314, 317, 464**
  - Compressed gas facility, **361**
  - Demographic features, **9, 13, 14, 19**
  - Drug companies, **296**
  - Infant development study, **673**
  - Munitions development, **711**
  - Neutron scattering experiments, **197**
  - Polymer science education, **205**
  - Productivity growth, **286, 408**
  - Railroad technology, **336**
  - Seabed mining, **765**
  - Space programs, **807**
  - *See also Research and development, Germany*
- **Global Atmospheric Research Program, 486**
- ***Global 2000 Report*, 475, 492, 506–507, 723, 762, 800**
- **Glomar Challenger (drillship), 166, 710**
- **Gold resources, 365, 366**
- **Government data collections, 554, 556, 611–613, 662–664**
- **Government/industry relationship, xxi, 281–282, 283–284, 304, 328, 418, 429–439, 463–464, 483, 754, 797**
- **Government regulations**
  - Centralization, **403, 405, 453**
  - Excess, **404, 443, 452, 453, 456, 557**
  - Federal vs. local control, **134, 140**
  - Vs. innovation/productivity, **xxviii, 295, 304**
  - Vs. international competitive position, **464, 468**
  - *See also Antitrust policy*
  - *See also Congressional Acts*
  - *See also Tax policy*
- **Government/university relationship, 279–280, 282, 328, 436, 437, 796, 797**
- **Graduate schools**
  - *See Universities*
- **Great Britain**
  - Aeronautical R&D, **346**
  - Demographic features, **9, 13, 14, 19**
  - Disease incidence, **40, 54**
  - Drug companies, **296**
  - Energy development, **302, 303**
  - Particle physics facilities, **261, 265**
  - Productivity growth, **286, 408**
  - Radioactive waste management, **147, 150, 303**
  - Risk assessment, **446, 456**
  - Space research, **720, 725, 807**
  - Unemployment, **463**
  - Water pollution control, **133, 135**
  - *See also Research and development, Great Britain*
- **Great Lakes, 335, 802**
- **Greece**
  - Demographic features, **9**
- **Green River oil shale, 319, 329**
- **Greenhouse effect, xxv, 4, 16, 160, 161, 162, 325, 468, 480, 742, 756, 800, 805**
- **Gross National Product (GNP) projections, 507, 800**
- **Guatemala**
  - Energy-efficient stoves, **477**
- **Guinea**
  - Bauxite resources, **518**
- **Gulf Coast**
  - Energy development, **310, 323**
  - Waste Disposal Authority, **135**

H

- **Handicapped education, 76, 794, 795, 796**
- **Harvard University, 402, 419, 430, 437**
- **Hazardous materials**
  - *See Toxic substances*
- **Head Start, 76, 591, 613**
- **Health and Human Services, Department of (HHS), 727–734, 782**
  - *See also specific parts*

Page numbers i–385 are in the first *Source Volume;* page numbers 387–807 are in the second *Source Volume.*

- **Health and medicine, 27–57, 561–588, 727-734**
  - Defense concerns, 715–716
  - Developing countries, 476, 477, 805–806
  - Health care delivery, xxix, 575, 734
  - Information systems, 90, 714, 734
  - Information transfer, 56–57, 728, 733–734
  - Instrumentation, 43, 350–353, 374–375, 447–448, 449
  - International research cooperation, 486, 801, 806
  - Lifestyle factors, 29–30, 35, 40–41, 51, 546, 561–588, 729, 731–732
  - Manpower, xxv, 797
  - Research, xxiii, 18, 56, 57, 279, 282, 728
  - Space concerns, 719, 722
  - Technology assessment, 734
  - *See also National Institutes of Health*
  - *See also specific disorders*
- **Health Effects Institute, 454**
- **Heart diseases**
  - *See Cardiovascular disorders*
- **High blood pressure**
  - *See Hypertension*
- **High-Energy Astronomy Observatory (HEAO), 720–721**
- **Highway transportation, 300, 333, 344, 776, 777, 780**
  - *See also Automobile transportation*
  - *See also Truck transportation*
- **Hitachi, 414**
- **Hoffman-La Roche, 730**
- **Hoover Institute, 550**
- **Human-computer interaction**
  - *See Man-machine interface*
- **Human development, 546, 553–554, 623–625 669–695**
- **Human experimentation, 572, 716**
- **Human resources**
  - *See Employment*
- **Hungary**
  - Demographic features, 9
- **Hybridoma technology, 43, 352, 728–729, 730**
- **Hydrogen (energy production), 316, 325, 361, 747**
- **Hydropower, 748**
- **Hypertension, 7, 29, 34, 50, 568–571, 582–583, 729–730**

I

- **IBM, 416**
- **Illinois**
  - Chicago subway system, 340
  - Coal reserves, 337
- **Imaging systems, 43, 293, 350–351**
- **Immigration**
  - *See Migration*
- **Immigration Acts, 13, 14**
- **Immunology, 53, 56, 67, 294, 352–353, 354, 574–575, 583, 728–729, 730**
- **Imports**
  - *See Foreign trade*
- **India**
  - Agricultural production, 477–478, 484, 491, 500
  - Cancer, 40
  - Demographic features, 5, 6, 10, 11, 506, 509, 510
  - GNP growth, 507
  - Landsat stations, 764, 807
  - Natural radiation, 141
  - Space/satellite programs, 725, 807
- **Indiana**
  - Steel industry, 517
- **Indonesia**
  - Demographic features, 10, 11, 20, 509
  - Liquefied natural gas resources, 741
  - Volcanic eruption, 162
- **Industrial automation**
  - *See Robots*
- **Industrial innovation, xxi, 407–419**
  - Government stimuli, 281–282, 283–284, 418
  - Management practices relationship, xxvii–xxviii, 399–400, 404, 407–409, 414–419, 557, 662
  - *See also Innovation*
  - *See also Productivity*
- **Industrial Innovation, Domestic Policy Review on, 418**
- **Industry (general)**
  - Diversification, 399, 416–417
  - Government/industry relationship, xxi, 281–282, 283–284, 304, 328, 418, 429–439, 463–464, 483, 754, 797
  - Management strategies, xxvii-xxviii, 399–400, 404, 407–409, 414–419, 557, 662
  - Research and development, xxviii, 256, 278, 285–288, 304, 399–400
  - Research expenditures, 286, 397, 409
  - Resource and energy constraints, 304, 519–520
  - Technology transfer to other countries, 463, 483
  - University/industry relationship, 255, 281, 282, 419, 430, 436, 437–438, 728, 779, 797, 798
  - *See also Industrial innovation*
  - *See also Multinational companies*
  - *See also Research and development, France, Germany, Great Britain*
  - *See also specific industries*
- **Infants**
  - Development, 553–554, 672–674
  - Mortality, xxix, 6, 7, 61, 510
- **Infection, 28, 54, 66–67**
- **Infectious diseases, 27, 444, 562, 574–575, 715, 729**
- **Inflation, 256, 296, 400, 462–463**
- **Information flow/dissemination**
  - Government role, 423–424, 428, 663
  - Health research, 56–57, 728, 733–734
  - Science and technology, 423–424
  - Transnational, 426, 469, 483–484, 758, 806
- **Information gathering**
  - *See Data bases*
  - *See Survey methodologies*
- **Information management, 425–426, 428, 605, 724-725**
- **Information overload, 425, 715**
- **Information processing**
  - *See Artificial intelligence*
  - *See Computers*
  - *See Decisionmaking (human)*
- **Information technologies, 421–428, 758, 792–793**
  - International issues, 426, 469, 483–484, 758, 806
  - Societal impacts, 401, 404, 423
  - U.S. leadership, 426
  - *See also Communications equipment/technologies*
- **Infrared Astronomy Satellite, 720**
- **Innovation**
  - Evaluation, 287, 558–559, 661
  - *See also Industrial innovation*
  - *See also Science and technology, Societal effects*
- **Institute for . . .**
  - *See other part of name*
- **Institutional Biosafety Committees, 433**
- **Insulin, 46, 47–49, 50, 51, 294, 355, 432, 728, 754**
- **Integrated pest management, 101, 116, 120, 772, 784, 785**
- **Intelligence, artificial, 89–91, 371–374, 706–707, 714, 755, 794**
- **Intelligence, human, 86–89, 555, 633-637**
- **INTELSAT, 178, 179**
- **Inter-American Foundation, 486**
- **Interagency Arctic Policy Group, 804**
- **Interagency Plant Sciences Committee, 801**
- **Interagency Radiation Research Committee, 731**
- **Interagency Regulatory Liaison Group, 453, 455**
- **Interagency Review Group on Nuclear Waste Management, 453**
- **Interagency Task Force on Acid Precipitation, 769**
- **Interagency Task Force on Tropical Forests, 762**
- **Interferon, 45, 294, 352, 355, 432, 728, 754**
- **Intergovernmental Maritime Consultative Organization (IMCO) Marine Pollution Convention, 805**
- **Interior, Department of the, 140, 763, 764, 802**
  - *See also specific parts*
- **Intermagnetics General, 357**
- **Internal Revenue Service, 611–612**
- **International affairs, 461–531, 799–807**
- **International Agricultural Development Service, 500**
- **International Commission on Radiological Protection (ICRP), 142, 143**
- **International Conference on Agricultural Production—Research and Development Strategies for the 1980s, 496**
- **International Council for the Exploration of the Seas, 804**
- **International Decade of Ocean Exploration (IDOE), 756**
- **International Development Cooperation Agency, (IDCA), 498**
- **International Development Institute, 487**
- **International Energy Agency (IEA), 303, 464, 802**
- **International Food and Agricultural Development, Board on, 499**
- **International Fund for Agricultural Development, 801**
- **International Geophysical Year (IGY), 174, 177, 181**
- **International Institute for Cotton (IIC), 484**
- **International Institute of Applied Systems Analysis, xxvi, 464**
- **International Labour Organization, 508**
- **International Magnetospheric Study, 177**
- **International organizations, 547**
  - *See also specific organizations*
- **International Polar Year, 177**
- **International Research and Exchanges Board, 551**
- **International research cooperation, 278–279, 283, 464, 466, 472, 473, 475–490, 800**
  - Agriculture, 466–467, 477–478, 480, 484, 486, 496, 498–500, 801
  - Air pollution control, 480, 804–805
  - Arid lands management, 803
  - Climate and weather, 177, 479, 486, 803–804
  - Ecology, 478–479, 480
  - Energy, 303, 304, 464, 477, 478, 486–487, 802
  - Health and medicine, 486, 801, 806
  - Mechanisms, 466, 473, 485–488
  - Oceans/polar regions, 479, 756, 804, 805
  - Social sciences, 550, 551
  - Space/satellites, 177, 181, 720, 725, 755, 806–807
  - Waste management, 805
  - *See also United Nations*
  - *See also specific organizations and programs*
- **International Rice Research Institute, 479**
- **International Service for National Agricultural Research, 500**
- **International Solar Polar Mission, 169**
- **International studies, 547–548, 557**
- **International Sun-Earth Explorers (ISEE), 171–172, 721**
- **International Telecommunications Union, 426, 484**

Page numbers i–385 are in the first *Source Volume*; page numbers 387–807 are in the second *Source Volume*.

- **International trade**
  - *See Foreign trade*
- **International Years of the Quiet Sun program, 177**
- **Interplanetary Physics Laboratory (IPL), 172**
- **Interstate Commerce Commission (ICC), 336**
- **Iraq**
  - Cancer, 40
  - Demographic features, 10
- **Ireland**
  - Cardiovascular disorders, 729
  - Demographic features, 9
- **Iron resources, 364, 366**
- **Irrigation, 125, 130, 754, 783**
- **Israel**
  - Bilateral agreements with U.S., 483, 485
  - Cancer, 40
  - Cardiovascular disorders, 31
  - Demographic features, 9
- **Italy**
  - Demographic features, 9
  - Drug companies, 296
  - Landsat stations, 764, 807
  - Productivity growth, 408
  - Space/satellite programs, 807

J

- **Jamaica**
  - Bauxite resources, 518
  - U.S. mineral imports from, 364
- **Japan**
  - Agricultural production, 16, 493, 499
  - Cancer, 40
  - Chemical industry, 291
  - Cognition research, 91
  - Demographic features, 7, 8, 9, 506
  - Drug companies, 296
  - Earthquake prediction, 764
  - Electronics industry, 290, 358, 399, 408, 409–413
  - Energy development, 303, 464
  - Foreign dependence, 468, 518
  - Genetic survey, xxvii
  - Labor/management, 399, 414–416, 418, 492–493, 555
  - Landsat stations, 764, 807
  - Productivity growth, 286, 408
  - Polymer science education, 205
  - R&D expenditures/growth, xx, 286, 409
  - Robotics, 90, 707, 779
  - Sci/tech education, 796
  - Seabed mining, 366, 765
  - Space/satellite programs, 725, 807
  - Steel industry, 517
  - Transportation industries, 298, 335, 336, 346, 414
- **Japan Victor, 413, 414**
- **Joint European Torus, 279**
- **Jupiter, 722, 755**
- **Justice Department, 418**
  - *See also Supreme Court decisions*
- **JVC, 413, 414, 415**

K

- **Kentucky**
  - Paducah gas centrifuge enrichment plant, 746
- **Kenya**
  - Crop production, 500
  - Demographic features, 6, 503
- **Kidney disorders, 66, 568**
- **Kitt Peaks Observatory, 256**

L

- **Labor force**
  - *See Employment*
- **Labor management**
  - *See Management practices*
- **Labor Statistics, Bureau of (BLS), 595**
- **Laboratory experimentation, 133, 583, 671**
- **Land-grant universities, 255, 282, 498**
- **Land Management, Bureau of, 762, 763**
- **Land use, 131, 723, 782–783**
- **Landsat, 469, 724, 764, 807**
- **Lasers, xxiii, 218, 293, 709, 716, 758–759**
- **Latin America**
  - Demographic features, 5, 6, 10, 12, 14, 505
  - GNP growth, 507
  - *See also specific countries*
- **Law of the Sea, 469, 765, 805**
- **Lawrence Livermore National Laboratory, 358, 709**
- **Lead imports, 364**
- **Less developed countries**
  - *See Developing countries*
- **Life expectancy, 4–7, 18, 27–28, 61, 68–69, 444–446**
- **Lifespan perspective, 546, 621–648**
- **Lifestyle/health relationship, 29–30, 35, 40–41, 51, 546, 561–588, 729, 731–732**
- **Linguistics, 79, 84–85**
- **Liquefied natural gas, 741, 780**
- **Liquid fuels**
  - *See specific fuels*
- **Lister Hill Center for Biomedical Communications, 734**
- **Liver disorders, 38, 65–66**
- **Livestock productivity, 498, 782, 784–785**
- **Louisiana**
  - Baton Rouge port facility, 337
  - Grand Isle water desalting plant site, 763
- **Love Canal, 452, 454, 768**
- **Lowell Observatory, 161**

M

- **McKinsey Award, 408**
- **Macromolecular science, xxii–xxiii, 183–206**
- **Magnesium resources, 17, 18, 712**
- **Magnetohydrodynamics, 301, 303, 357, 358**
- **Maine**
  - Environmental concern, 447
- **Malaysia**
  - Liquefied natural gas resources, 741
  - Rubber production, 484
  - U.S. mineral imports from, 364
- **Malnutrition, 18–19, 66, 492, 786, 805**
- **Man-machine interface, 76, 714–715, 780**
- **Management and Budget, Office of, 472**
- **Management practices**
  - Industrial innovation relationship, xxvii–xxviii, 399–400, 404, 407–409, 414–419, 557, 662
- **Manganese resources, 364, 365, 518, 519, 520, 765, 804**
- **Manhattan Engineer District/AEC sites, 745**
- **Manpower**
  - *See Employment*
  - *See Scientists and engineers*
  - *See also under Research and development*
- **Mansfield Amendment of 1969, 400**
- **Mapmaking, 237–243, 251**
- **Marine**
  - *See Oceans*
- **Marine transportation, 334–335, 337, 338, 341, 343, 345, 346–347, 805**
- **Mariner 9 mission, 722**
- **Marital patterns**
  - *See Family characteristics*
- **Maritime Administration, 347**
- **Mars, 160, 722, 755**
- **Maryland**
  - Asian flu study, 575
  - Baltimore port facility, 337
- **Mass transit, 338, 340, 341, 476, 777, 778**
- **Massachusetts**
  - Cambridge Experimentation Review Board, 430, 434
  - Recombinant DNA debate, 402, 429, 430
- **Massachusetts Institute of Technology, 275, 278, 402, 419, 429**
- **Materials**
  - Synthesis, 183–226, 711–713, 751, 757
  - *See also Resources*
- **Mathematics, xxiii, 231–252, 372–373, 757**
- **Matsushita, 411, 412, 413, 414, 415**
- **Medical Applications of Research, Office for (OMAR), 734**
- **Medical technology, 43, 350–353, 374–375, 447–448, 449**
- **Medicine**
  - *See Health and medicine*
  - *See specific disorders*
- **Andrew W. Mellon Foundation, 550**
- **Mental disorders, 731–732, 733**
- **Merchant Marine Act of 1936, 1970 Amendments, 334**
- **Methane, 312, 316–317, 322, 325, 327, 329, 741, 789**
- **Methanol, 208, 312, 313, 317, 322, 323, 325, 329**
- **Mexico**
  - Agricultural production, 500, 801
  - Arid lands management, 763, 803
  - Demographic features, 4, 10, 12, 13, 506
  - Natural gas resources, 740
  - U.S. mineral imports from, 364
  - Water quality concerns, 802
- **MHD Component Development and Integration Facility, 358**
- **Michigan**
  - Endangered species policy, 100
  - PBB poisoning, 731
- **Michigan State University**
  - Field bean/cowpea program, 499
- **Michigan, University of**
  - Institute for Social Research, 549–550
- **Middle Atmosphere Program, 177**
- **Middle East**
  - Demographic features, 10
  - Internal stability, 508
  - Locust threat, 478
  - *See also specific countries*
- **Migration, 5, 12–15, 19–20, 443, 467, 479, 505, 508, 510**
- **Military**
  - *See Defense*
- **Mine Safety and Health Act, 452**
- **Minerals**
  - *See Nonfuel minerals*
  - *See specific minerals*
- **Mines, Bureau of, 366, 468**
- **Mining, 118, 151, 319, 323, 327, 366, 742, 743**
- **Minnesota**
  - Twin Cities wastewater management, 135
- **Mississippi River, 335, 337**
- **Missouri/Yellowstone river basin, 125**

Page numbers i–385 are in the first *Source Volume*; page numbers 387–807 are in the second *Source Volume*.

Mobil, 317, 323
Molybdenum resources, 364, 366
Monsanto, 419
Montana
    Chromite deposit, 366
    MHD facility, 358
Morrill Act of 1863, 255
Mortality, xxix, 5–8, 22–23, 28, 61, 444–446, 503, 562, 564, 584–585
Motility (biological organisms), 203–205
Motor Carrier Act of 1935, 336
Motor vehicles
    See Automobiles
    See Trucks
Mount Palomar Observatory, 256, 370
Mount St. Helens, 162, 764
Mozambique
    Cancer, 40
Multinational companies, 296, 303, 463, 465, 483, 529, 547, 548, 554
Muscles, 203–205, 581

N

National Academy of Peace and Conflict Resolution, 470, 527, 528
National Acid Precipitation Program, 769
National Aeronautics and Space Act of 1958, 718
National Aeronautics and Space Administration, (NASA), 169, 172, 176, 181, 298, 339, 342, 345, 347, 486, 708, 717–725, 749, 762, 763, 764, 773, 782, 792, 796, 807
National Ambient Air Quality Standards (NAAQS), 324
National Bureau of Economic Research, 550
National Bureau of Standards, 453
National Cancer Institute, 35, 126, 730, 731
National Center for Health Services Research, 734
National Center for Toxicological Research, 455
National Climate Program, 773, 803
National Commission on Libraries and Information Science, 424
National Council of Churches, 438
National Council on Radiation Protection and Measurement, 142, 452
National Defense Education Act of 1958, 550
National Earth Satellite Service (NESS), 724
National Earthquake Hazards Reduction Act, 452
National Endowment for the Humanities, 550–551
National Energy Conservation Policy Act, 302
National Environmental Protection Act, 96, 133, 140
National Fire Prevention and Control Administration, 452
National Gas Policy Act of 1978, 747
National Heart, Lung and Blood Institute (NHLBI), 730
National Institute for Occupational Safety and Health (NIOSH), 402, 433, 731
National Institute of Education (NIE), 795
National Institute of Environmental Health Sciences (NIEHS), 731
National Institute of Mental Health (NIMH), 792
National Institute on Alcohol Abuse and Alcoholism (NIAAA), 732
National Institute on Drug Abuse (NIDA), 732, 733
National Institutes of Health (NIH), xxiv, xxv, 279, 282, 453, 550, 582, 734, 792, 796, 797, 801
    Recombinant DNA guidelines, 353, 402, 404, 430, 431–433, 434, 439, 728
    See also specific parts
National laboratories, 256, 257, 278, 796
    See also specific laboratories
National Library of Medicine, 731, 733
National Materials and Minerals Policy, Research and Development Act of 1980, 765
National Oceanic and Atmospheric Administration (NOAA), 721, 724, 762, 764, 765, 769, 773, 802, 804
National Opinion Research Center, 549–550, 601, 603, 607
National Park Service (NPS), 762
National Science and Technology Policy, Organization and Priorities Act of 1976, i, xvii, 389
National Science Board, 660, 661
National Science Council proposal, 452, 454
National Science Foundation (NSF), xix, xx, xxiv, 256, 279, 280, 368, 423, 453, 498, 550, 551, 660, 762, 763, 773, 792, 795, 802
National security
    See Defense
National Technical Information Service (NTIS), 483
National Toxicology Program, 450, 453, 731
National Uranium Resource Evaluation Program, 367
National Weather Service, 764
Natural gas, 309–310, 311, 737, 739, 740–741, 746
Natural hazards, 162, 445, 450, 451, 455, 723, 755, 756, 764–765
Natural resources
    See Resources
    See specific resources
Navy, Department of the, 180, 706, 707, 708, 712
Nebraska
    Cropping systems, 116
Neptune, 161
Netherlands
    Aeronautical R&D, 346
    Demographic features, 9
    Productivity growth, 408
    Space/satellite programs, 720, 807
Neurobiology, 63, 76–77, 294, 574, 575, 576–577, 583, 731–732, 733, 755
Nevada
    Gold deposits, 365
    Volcanic tuff sites, 151
New Caledonia
    U.S. mineral imports from, 364
New Jersey
    Environmental concerns, 446
    Negative Income Tax Experiment, 591, 610, 611
New Mexico
    Volcanic tuff sites, 151
    Waste Isolation Pilot Plant, 152
    Water desalting plant site, 763
New York State
    Love Canal, 452, 454, 768
    Water resources contamination, 128, 132
New Zealand
    Demographic features, 9
    Synthetic fuels, 317
Nickel resources, 364, 520, 765, 804
Nigeria
    Cancer, 40
    Demographic features, 10, 12
    Liquefied natural gas resources, 741
Nimbus satellites, 161, 176
Nixon, Richard, 14
Nobel Prizes, 232, 255, 259, 271, 278, 429
Noise Control Act, 452
Noise pollution, 299, 345–346, 716
Nonfuel minerals, 16–17, 363–368, 517–521, 765, 803
    See also Resources
    See also specific minerals
North America
    Demographic features, 9, 12, 14, 505
    See also specific countries
North Atlantic Treaty Organization, 261, 471, 710
North Carolina
    Fort Bragg packet radio network, 708
Norway
    Demographic features, 7, 9
    Satellite programs, 807
Nuclear fission, 16, 302, 303, 743–746
    Developing countries, 478, 486
    Risks/safety, xxv, xxvi, 139, 146, 445, 446, 447, 451, 452, 454, 470, 745
Nuclear fusion, 16, 177, 182, 358, 745, 751–752
Nuclear Regulatory Commission, 140, 142, 447, 452, 744
Nuclear Safety Analysis Center, 454
Nuclear waste management, xxvi, 139–155, 453, 744–745
Nuclear weapons, 525, 529–530, 752
    Testing, 142, 148, 710, 731
Nutrition, xxiii, 59–73, 785–787

O

Oak Ridge National Laboratory, 147, 148, 197, 358, 746
Obesity, 49, 51, 61–64, 445, 569
Occidental Petroleum, 321
Occupational health and safety, 142, 403, 433, 445, 449, 453, 455, 731
Occupational Safety and Health Act, 452
Occupational Safety and Health Administration, 402, 449, 450, 452, 453, 728, 731
Ocean Science in Relation to Living Resources Program, 804
Ocean thermal energy conversion (OTEC), 749, 804
Oceans, 756
    Ecosystems, 99, 101, 102
    Energy resources, 749, 804
    Fishery resources, 765–766, 804, 805
    International research cooperation, 479, 756, 804, 805
    Jurisdictional issues, 365, 469, 479, 765, 804
    Mineral resources, 365–366, 479, 520, 765, 804
    Nuclear test verification, 710
    Pollution, 766, 805
    Waste disposal, 147–148, 153, 805
Office of . . .
    See other part of name
Ohio
    Environmental concern, 446
    Portsmouth Gas Centrifuge Enrichment Plant, 746
Ohio River, 335, 337
Ohio River Valley Sanitation Commission, 134, 135
Oil
    See Petroleum
Oil shale, 310, 311, 317, 318, 319–321, 323, 324, 326, 327, 329, 342, 739, 740
OPEC, 22, 507, 517
Optical fibers, 222–223, 290, 758, 793
Organ failure, 65–66
Organization for Economic Cooperation and Development (OECD), 285, 464, 660–661, 802
Organizational behavior, 404–406, 548, 659, 665
Origin of Plasmas in the Earth's Neighborhood (OPEN) Program, 172
Ozone, 159, 161, 175, 176, 177–178, 480, 756, 800, 805

Page numbers i–385 are in the first *Source Volume;* page numbers 387–807 are in the second *Source Volume.*

P

- **Pacific Coast**
  - Ecosystems research, 99, 101
- **Pacific Ocean**
  - Radioactive debris, 148
  - Seabed mineral resources, 365, 765
- **Pain research**, 215, 576–577, 580, 581
- **Pakistan**
  - Agricultural production, 491, 500
  - Demographic features, 10, 12, 503, 509
  - GNP growth, 507
- **Panama**
  - Copper resources, 518
- **Paperwork, Commission on Federal**, 424
- **Paperwork (government)**, 425
- **Papua New Guinea**
  - Copper resources, 518
- **Parenteral nutrition**, 59, 67–68
- **Parks and nature reserves**, 101, 479, 797
- **Particle physics**, 163–164, 182, 197, 357, 358, 709, 756–757
- **Patent Act of 1790**, 436
- **Patents**
  - Living organisms, 435–436, 438
  - Software, 427
- **Peace Corps**, 802
- **Peace research**, 470, 527–528, 529
- **Pennsylvania**
  - BLITECAST forecasting system, 116
  - Philadelphia, Hahneman Community Mental Health Center program, 676
  - Prison population, 655
  - Steel industry, 517
  - Three Mile Island, 139, 452, 454, 731
- **People's Republic of China**
  - *See China, People's Republic of*
- **Peptic ulcer**, 571–573
- **Personality factors in disease**, 29, 566–568, 570, 583, 584
- **Peru**
  - Mineral exploration studies, 368
  - U.S. mineral imports from, 364
- **Pest management**
  - *See Integrated pest management*
- **Petroleum**
  - Exploration/processing, 303, 321–322, 327–328, 514, 738–740, 804
  - Spills, 345, 770, 805
  - Supply and demand, xxv, 16, 309–310, 311, 313, 516, 517, 519, 520, 736, 737, 739, 740, 777
  - *See also Gasoline*
- **Petroleum industry**, 286, 302
- **Pharmaceutical industry**, xxviii, 293–296, 467, 485
- **Philippines**
  - Demographic features, 10, 503
  - Rice production, 479, 500
- **Philips**, 411, 412, 413, 414, 415
- **Phosphate resources**, 364, 365
- **Phosphorus resources**, 17
- **Photographic products**, 292–293
- **Pipeline transportation**, 180, 337, 746
- **Placebo effect**, 576
- **Plant Patent Act of 1930**, 436
- **Plant Variety Protection Act of 1970**, 436
- **Plants**
  - Biological/genetics research, xxix, 103, 112–113, 116, 117–118, 120, 496, 751, 754, 783–784
  - Diseases, xxix, 111–121
  - Population biology, 98, 102–103
  - Source of materials, 211, 788–789
  - *See also Biomass*
  - *See also Crop productivity*
- **Plastics industry**, 292, 711
- **Platinum resources**, 364, 365, 518, 519, 765
- **Poland**
  - Demographic features, 9
  - Satellite programs, 807
- **Polar Plasma Laboratory (PPL)**, 172
- **Polar regions**, 161, 175, 177, 804
- **Policymaking**
  - Complexity, 401
  - International dimension, 471–473, 476–477, 480, 487, 489
  - Public participation in, 153, 404, 405, 429, 430, 434–435 446–447, 451–452, 470
  - S&T role in, 393–394
  - Social science data in, 547, 556–557, 562, 590–591, 607–608, 613–614, 631, 641–643, 650, 671–672, 691
  - *See also Science policy*
- **Pollution**
  - *See specific types of pollution*
- **Polymers**, 183–206, 291–292, 788
- **Population growth**, 479, 480, 503–511, 800–801
  - Predictions, 3, 20, 22, 325, 505–506, 783, 800
  - Vs. resources, xxviii, 3–4, 15–18, 20–22, 466, 467, 492, 506–508, 755, 762, 783, 800
  - *See also Current population survey*
  - *See also Demography*
  - *See also Family planning*
  - *See also specific demographic variables*
- **Portugal**
  - Demographic features, 9
- **Postal Service**, 427
- **Potash resources**, 364, 519
- **Potomac River estuary**, 136
- **Presidential debates**, 654
- **Presidential elections**
  - 1972, 596
  - 1976, 654
  - 1980, 604, 654
- **President's Commissions**
  - Ethical Problems in Medicine, 436
  - Three Mile Island, 452
  - World Hunger, 18, 494
- **President's Nonfuel Minerals Policy Study**, 519, 521
- **President's Science Advisory Committee**, 454
  - *See also Science advisory groups*
- **Princeton University**
  - Tokamak Fusion Test Reactor, 177, 358, 751
- **Privacy (information)**, 425, 428, 469, 600, 612, 758
- **Productivity**, 304, 521
  - Growth, 286, 304, 398, 408
  - R&D relationship, 286–287, 398, 399–400, 408
  - Social innovations relationship, 662
  - *See also Industrial innovation*
  - *See also Innovation*
- **Psychology**
  - *See Behavior*
- **Psychosocial factors in disease**, 561–588, 732
- **Public concerns/participation in policymaking**
  - Defense spending, 470
  - Environment, 446–447
  - Nuclear power/wastes, xxvi, 139–140, 153, 452, 743
  - Recombinant DNA, 402, 404, 429, 430, 431, 434–435
  - Risks (general), 450–452
  - Science and technology, 374, 405, 661, 795, 797

Q

- **Quality of life measurement**, 659

R

- **Racial factors**
  - Economic achievement, 632, 652–653
  - Hypertension, 568
  - Life expectancy, 18, 444
  - Migration, 15
- **Racial integration**, 656, 657
- **Radiation**, 141–144
  - Health care, 43–44, 141, 351, 730
  - Health effects, xxvii, 37, 39–40, 142, 144, 153, 731, 771
  - *See also Nuclear waste management*
- **Radio frequency spectrum**, 179, 426, 484, 806
- **Radioactive waste management**
  - *See Nuclear waste management*
- **Radiological Protection, International Commission on (ICRP)**, 142, 143
- **Rail transportation**, 335–336, 337, 347, 776–777
  - Electric power, 342, 347, 778
  - Energy concerns, 338, 340, 341, 342
  - Pollution, 345, 346
  - Safety, 343, 344
- **Rand Corporation**, 550
- **Raw materials**
  - *See Resources*
  - *See specific materials*
- **RCA**, 411, 412, 414, 415
- **Reagan, Ronald (Administration)**
  - Economic Recovery Program, 736–737, 744
  - Election, 557, 604, 654
  - Energy policy, 736–737, 738, 744, 745, 747
  - Foreign policy, 468, 489
  - Minerals policy, 765
  - National Economic Emergency, 407
  - Regulatory reform, 404, 453, 464, 747
- **Recombinant DNA**, 353–355, 374, 429–441, 728, 753, 754
  - Agricultural applications, 112, 116, 117, 120, 353, 432, 728, 784
  - Chemical/drug applications, 50, 294, 355, 375, 432, 728, 730
  - Energy applications, 355, 432
  - Ethical issues, 430, 436, 438–439
  - Genetic research applications, 353–354
  - Immunological research applications, 354, 729
  - NIH guidelines, 353, 402, 404, 430, 431–433, 434, 439, 728
  - Risk/benefit analysis, 401–402, 404, 431, 433–434, 452
  - Technique, 353, 430–431
- **Recommended Dietary Allowances (RDA)**, 70–71
- **Recordkeeping (government)**, 611–613, 662–664
- **Red Sea spreading centers**, 365
- **Refugees**, 5, 13, 15, 508
- **Regulations**
  - *See Congressional Acts*
  - *See Government regulations*
- **Regulatory Analysis Review Group**, 453
- **Regulatory Council**, 453
- **Relaxation training**, 581
- **Remote sensing**, 486, 719, 723–724, 755, 756, 764, 807
- **Renewable resources**
  - *See under Resources*
- **Reproduction, animal**, 105–107
- **Reproduction, human**, 455, 509, 510
- **Republic of . . .**
  - *See other part of name*
- **Research and development, France**, 265–271
  - Basic, 267–268
  - Centralization, 265–266
  - Comparison with U.S., 255, 258, 265, 278–284, 286

(continued)

Research and development, France, (continued)
  Cooperation, international, 269, 270, 278–279, 283
  Expenditures, 258, 268–269, 409
  Government/industry/university relationship, 265, 266–267, 270, 281, 283–284
  Government laboratories, 255, 265, 266, 267, 270, 278
  Government support, 258, 268–269, 279–280
  Grants/types of projects, 267, 269, 279–280, 283
  Industry, 269, 278
  Instrumentation, 270–271
  Manpower, 266, 269–270, 271, 281, 283
  Organization of, 265–268, 278–279, 282, 283
  Peer review, 280, 281
  Priority selecting, 266, 267, 268–269
  Scientists in decision making, 267
  Strengths and weaknesses, 271
  Universities, 265, 267, 268, 270, 278, 279–280
Research and development, Germany, 271–278
  Applied, 272, 273, 274
  Basic, 271, 273–274
  Comparison with U.S., 255, 258, 278–284, 286
  Cooperation, international, 274, 278–279, 283
  Decentralization, 271, 272, 273
  Expenditures, 258, 272, 274, 409
  Government/industry relationship, 272, 281, 283–284
  Government research institutes, 273, 278
  Government support, 258, 272, 274–276, 277, 279–280
  Grants/types of projects, 272, 274–275, 277, 279–280, 283
  Industry, 273–274, 278
  Instrumentation, 275
  Manpower, 276–277, 281, 283
  Organization of, 271–274, 275, 278–279, 282, 283
  Peer review, 280, 281
  Priority selecting, 272, 273
  Private foundations funding, 275, 277
  Strengths and weaknesses, 277–278
  Universities, 272, 273, 274, 275, 276, 277, 278, 279–280
Research and development, Great Britain, 259–265
  Applied, 260, 262–263
  Basic, 258, 259, 261, 262
  Comparison with U.S., 255, 258, 278–284, 286
  Cooperation, international, 261–262, 263, 265, 278–279, 283
  Decentralization, 260
  Expenditures, 258, 263, 409
  Government/industry/university relationships, 262–263, 281, 283–284
  Government laboratories, 259, 261, 263, 265, 278
  Government support, 258, 259, 260, 263–264, 279–280
  Grants/types of projects, 259, 260, 261, 263, 279–280, 283
  Industry, 261, 263, 278
  Instrumentation, 263, 265
  Manpower, 263, 264–265, 281, 283
  Organization of, 259–260, 261–263, 278–279
  Priority selecting, 259–260, 260–261
  Scientists in decision making, 260–261
  Universities, 259, 260, 261, 263, 264–265, 278, 279–280
Research and development, U.S., 255–259
  Administrative burdens, 256–257, 401
  Applied, 256, 282
  Basic, 255–256, 258, 286, 304, 753–754
  Comparison with Europe, 255, 258, 259, 278–284, 286, 409
  Domestic orientation, 461, 462, 466
  Expenditures, xxii, 258, 285–286, 397, 409, 466
  Government support, xix, xx, xxi–xxii, xxiii–xxiv, 256, 258, 279–280, 281, 282, 283, 286, 304, 397, 400–401, 436
  Grant and contract projects, xxiv, 258, 280, 796–797
  Industry, xxviii, 256, 278, 285–288, 304, 399–400
  Instrumentation, 256, 257, 283, 401
  International competition, xx–xxi, 304
  International implications, 461–473
  Manpower, xxiv, xxv, 257, 258–259, 281, 283
  Nonprofit institutions, 256, 278, 283
  Organization of, xxiii–xxiv, 255–258, 278–279, 282–283, 304
  Peer review, 261, 280–281
  Priority selection, xxiv
  Return on investment, xxi–xxii, 286, 399–400
  Short-term vs. long-term results, 257, 304, 399, 400, 401, 408, 416, 417, 557, 664
  Universities, 255–256, 257, 258, 278, 304, 549–550
  U.S. leadership role, xx–xxi, 255, 258, 282, 465, 475
  See also Industry
  See also International research cooperation
  See also Science and technology
  See also Scientists and engineers
  See also Universities
  See also specific industries
Research Apprenticeship Program for Minority High School Students (RAMHSS), 796
Research cooperation, international
  See International research cooperation
Research Triangle Institute, 550, 603
Resource Conservation and Recovery Act, 452
Resources
  Developing countries concerns, 484, 518–519, 765
  International security issues, 517, 519–521
  Recycling, 17, 300, 363, 749
  Renewable, 747–749, 788–789
  Supply and demand, 513–522
  Supply interruption strategies, 17,300, 467–468, 517, 519, 520–521, 765, 803
  Vs. population, xxviii, 3–4, 15–18, 20–22, 466, 467, 492, 506–508, 755, 762, 783, 800
  See also specific resources
Rheumatic diseases, 51–56
Risk Analysis, Society for, 454
Risk assessment, xxvii, 402–404, 443–458, 731
Risk/benefit analysis, xxvi–xxvii, 448–449
  Carcinogen regulation, xxvii, 42–43
  Drug testing, 295, 467, 485
  Pesticides, 772
  Radiation, xxvii
  Recombinant DNA, 401–402, 404, 431, 433–434, 452
  See also Cost/benefit analysis
Ritter, Congressman Don, 452
RNA, 39, 48, 119, 190–191
Robots, xxvi, 90, 291, 300, 419, 706–707, 739, 758, 779
Rockefeller Commission, 14
Rockefeller Foundation, 550
Romania
  Demographic features, 9
Rubber industry, 484
Rural areas, 14, 783, 789
Russell Sage Foundation, 550
Russia
  See USSR
Rutile resources, 365, 366

S

Safe Drinking Water Act of 1974, 126, 448, 452, 763, 773
Sahel Development Program, 763
Salk Institute, 278
SALT II, 470
Sandia National Laboratory, 751
Sanyo, 412, 414
Satellite-Aided Search and Rescue Communications System (SARSAT), 807
Satellites, 179
  Communications, 178–179, 332, 422, 724, 793, 806, 807
  Earth-monitoring, 469, 719, 723–724, 755, 756, 764, 803
  Space exploration, 171–172, 176, 180, 721–722, 755, 807
  See also Remote sensing
  See also specific satellites
Saturn, 161, 722, 755
Science advisory groups, 454–455, 456
Science and technology
  Appropriate technology, 465, 477, 486, 789, 801
  Foreign policy tool, 463, 468, 471, 476, 480, 526, 800
  Integrity, 454–455
  Interdisciplinary nature, xxiii
  Public concern/understanding of, 374, 661, 795, 797
  Societal effects, 287, 393, 397, 401–402, 404–406, 438–439, 461, 558–559, 660, 661–662, 665, 734, 788, 799
  Status, xx–xxi, xxii–xxiv, xxix, 397–398
  See also Research and development
  See also Risk/benefit analysis
  See also Science policy
Science and Technology Policy, Office of, 140, 452, 454, 487
Science and Technology Policy, Organization and Priorities Act of 1976, i, xvii, 389
Science education
  See Education (curricula)
Science Indicators, 660–661
Science policy, 405, 463, 547, 660–661, 665
Science, The Endless Frontier, xix
Scientific and Technological Cooperation, Institute for (ISTC), 466, 472, 487, 498–499
Scientists and engineers
  Employment in industry, 281, 601–602
  Employment in universities, 257, 281, 283
  Ethics, 438–439
  Public concern about, 431, 661
  Public vs. commercial interests, 436, 437, 438–439
  Supply and demand, xxv, 426, 471, 782
  See also Education (curricula)
  See also Manpower under Research and development
Scotland
  Cardiovascular disorders, 729
  Energy development, 303
Seabed
  Energy resources, 739, 804
  Jurisdictional issue, 365, 469
  Mineral resources, 365–366, 520, 765, 804
  Radioactive waste disposal, 148
Securities and Exchange Commission, 347
Sex differences
  Behavior, 575, 684–687, 689
  Cancer, 41, 573
  Cardiovascular disorders, 33, 568
  Economic achievement, 632–633
  Life expectancy, 5, 18, 28
  Mortality, 7, 444
Shale oil
  See Oil shale

Page numbers i–385 are in the first *Source Volume*; page numbers 387–807 are in the second *Source Volume*.

- **Ships**
  - *See Marine transportation*
- **Silver resources, 364**
- **Singapore**
  - Cancer, **40**
  - Fertility control, **510**
  - Urban transport planning, **476**
- **Skylab, 167, 168, 177**
- **Alfred P. Sloan Foundation, 550**
- **Smithsonian Institution, 762, 802**
- **Smoking**
  - *See Cigarette smoking*
- **Social behavior**
  - *See Behavior*
  - *See Psychosocial factors in disease*
- **Social Security, xxix, 9, 642**
- **Social Security Administration (SSA), 611–612**
- **Social trends (change)**
  - Measurement, **546, 649–667**
- **Societal effects of science and technology, 287, 393, 397, 401–402, 404–406, 438–439, 461, 558–559, 660, 661–662, 665, 734, 788, 799**
- **Societal well-being, 658–659, 665**
- **Society . . .**
  - *See other part of name*
- **Socioeconomic factors**
  - Fertility, **19**
  - Life chances, **629–633, 659–660**
  - Life expectancy, **6**
- **Soil, 21, 99, 130, 783**
- **Solar energy, 16, 446, 737, 747–748**
- **Solar Maximum Mission Satellite, 169, 181, 721, 807**
- **Solar Mesosphere Explorer, 176**
- **Solar Optical Telescope, 169**
- **Solar-terrestrial linkages, xxii, 160–182, 721–722**
- **Solar Thermal Central Receiver Pilot Plant, 301**
- **Solid fuels**
  - *See specific fuels*
- **Solid waste**
  - *See Waste management*
- **Sony Corporation, 399, 410, 412, 413, 414, 415, 416**
- **South Africa, Republic of**
  - Energy development, **303, 313, 317, 323**
  - Landsat stations, **764, 807**
  - Mineral resources, **518, 519**
  - U.S. mineral imports from, **364**
- **South Carolina**
  - Savannah River nuclear waste plant, **145, 147**
- **South Dakota**
  - Neutrino trap, **163**
- **South Korea**
  - Demographic features, **10**
  - Economic growth, **548**
- **Soviet Union**
  - *See USSR*
- **Space science, 159–182, 368–371, 709, 717–725, 755, 757, 806–807**
- **Space Shuttle, 169, 177, 368–371, 709, 718–719, 720, 722, 724, 796, 807**
- **Space Solar Power Station, 180**
- **Space Telescope, 370–371, 720**
- **Spain**
  - Demographic features, **9**
- **Special Education and Rehabilitative Services, Office of, 795**
- **Sputnik, 177**
- **Sri Lanka**
  - Demographic features, **6**
- **St. Lawrence Seaway, 335**
- **State, Department of, 470, 762, 782, 801, 802, 803**
- **Steel industry, 517, 519**
- **Stevenson-Wydler Technology Innovation Act of 1980, 408**
- **Sulfur resources, 364, 519**
- **Sun, xxii, 159–182, 721–722**
- **Superior Oil, 320**
- **Supreme Court decisions**
  - Patenting of living organisms, **435–436, 438**
  - Risk assessment, **453**
- **Survey methods, 546, 548–549, 589–619, 671**
- **Sweden**
  - Cardiovascular disorders, **31**
  - Demographic features, **7, 9, 19**
  - Landsat stations, **764, 807**
  - Productivity growth, **408**
  - Radioactive waste management, **146, 150, 151**
  - Satellite systems, **807**
- **Switzerland**
  - Demographic features, **9, 14**
  - Drug companies, **296**
  - Energy development, **303**
  - Genetics research, **754**
  - Particle physics facility, **357**
- **Syngas, 208, 291, 314, 317, 329**
- **Synthetic fuels, xxv, 303, 311–330, 342**
  - *See also specific fuels*
- **Synthetic Fuels Corporation, 311, 329, 740, 742**
- **Systematics, 96–97**

T

- **Taiwan**
  - Demographic features, **503**
  - Economic growth, **548**
- **Tar sands, 310, 317**
- **Tax policy**
  - Energy, **302, 311, 738, 747, 748, 749, 750**
  - Multinational companies, **296**
  - R&D investments, **400, 418, 463**
- **Tax Reform Act of 1976, 612**
- **Technology**
  - *See Science and technology*
- **Technology Assessment, Office of (OTA), 433, 438, 449, 452, 795**
- **Teenage pregnancy, 455**
- **Telecommunications**
  - *See Communications equipment/technologies*
- **Television, 410, 411, 422, 508, 679–680, 793, 806**
- **Tennessee Valley Authority, 763**
- **Texaco, 315**
- **Texas**
  - Smoking prevention program, **584**
  - Synthetic fuels plant, **317**
- **Texas Instruments, 416**
- **Textiles industry, 484, 519, 788**
- **Thailand**
  - Demographic features, **10**
  - Landsat stations, **764, 807**
- **Three Mile Island, 139, 452, 454, 731**
- **Tin resources, 364, 365**
- **Tiros, 724**
- **Titanium resources, 17, 364, 365, 366, 712**
- **Tobacco**
  - *See Cigarette smoking*
- **TOSCO Corporation, 320**
- **Toshiba, 412, 414**
- **Toxic substances**
  - Defense concerns, **716**
  - Exports, **484–485, 805**
  - Regulations, **403, 450, 454, 769**
  - Social aspects of control, **662**
  - Spills, **770**
  - Testing/measurement, **xxvii, 132–133, 403, 443, 731, 769**
  - Transportation, **146, 343–344, 777, 780**
  - *See also Air pollution*
  - *See also Carcinogens*
  - *See also Waste management*
  - *See also Water pollution*
- **Toxic Substances Control Act of 1976, 42, 132–133, 448, 450, 452, 769**
- **Toxicology, National Program, 450, 453, 731**
- **Toxicology, Society of, 455**
- **Tracking and Data Relay Satellite System (TDRSS), 724**
- **Trade**
  - *See Foreign trade*
- **Training**
  - *See Education*
- **Transnational companies**
  - *See Multinational companies*
- **Transportation, 331–348, 775–780**
  - Capacity, **332–337, 776–777**
  - Energy concerns, **296–297, 299, 301, 303, 304, 311, 337–342, 347–348, 736–737, 749–750, 777–778**
  - Energy resources transportation, **311, 326, 332, 337, 517, 746**
  - Environmental pollution, **299, 344–346, 452, 454, 771**
  - Foreign trade position, **346, 778–779**
  - Intermodal issues, **331, 336, 348**
  - Safety, **300, 342–344, 779–780**
  - Toxic substances, **146, 343–344, 777, 780**
  - *See also specific modes of transportation*
- **Transportation, Department of (DOT), 140, 298, 336, 339, 749, 763**
  - *See also specific parts*
- **Trinidad**
  - Liquefied natural gas resources, **741**
- **Tropical diseases, 509, 715, 805**
- **Tropical forests**
  - *See Forest resources*
- **Truck transportation, 339–340, 341, 344, 346, 749**
- **Tungsten resources, 364, 365**
- **Tunisia**
  - Demographic features, **503**
- **Turkey**
  - Demographic features, **10**
  - Rice production, **500**
- **Tuskeegee Institute, 498**
- **Type A behavior, 29, 566–568, 583, 584**

U

- **Uganda**
  - Cancer, **38, 40**
- **Unemployment**
  - *See Employment*
- **Union of Concerned Scientists, 455**
- **Union Oil Company, 320**
- **United Kingdom**
  - *See Great Britain*
- **United Nations, xxviii, 476, 527**
  - Arid land activities, **803**
  - Health activities, **806**
  - Information activities, **483**
  - Population activities, **505, 509, 550**
  - Telecommunication activities, **806**
  - *See also specific U.N. bodies*
- **United Nations Association of the United States, 489**
- **United Nations Committee on the Peaceful Uses of Outer Space, 725, 807**
- **United Nations Conference on the Exploration and Peaceful Uses of Outer Space (UNISPACE 82), 725, 807**
- **United Nations Council on Trade and Development (UNCTAD), 484**
- **United Nations Development Program, 801**
- **United Nations Economic Commission for Europe, 805**
- **United Nations Educational, Scientific, and Cultural Organization (UNESCO), 484, 758, 804, 806**

Page numbers i–385 are in the first *Source Volume;* page numbers 387–807 are in the second *Source Volume.*

United Nations Environment Program, 763, 803
United Nations Fund for Population Activities, 801
United Nations Interim Fund for Science and Technology for Development, 487, 801
United Nations Scientific Committee on the Effects of Atomic Radiation, 142
Universities, France
    See under Research and development, France
Universities, Germany
    See under Research and development, Germany
Universities, Great Britain
    See under Research and development, Great Britain
Universities, U.S.
    Employment of scientists, **257, 281, 283**
    Enrollment, **xxv, 257**
    Equipment, **401, 796, 798**
    Government/university relationship, **279–280, 282, 328, 436, 437, 796, 797**
    Industry/university relationship, **255, 281, 282, 419, 430, 436, 437–438, 728, 779, 797, 798**
    Research and development, **255–256, 257, 258, 278, 304, 549–550**
    Research support, **279–280, 282, 436, 437**
    See also Education (Curricula)
    See also specific universities
University of . . .
    See under state name
Upper Atmosphere Research Satellites, 176, 724
Upper Volta
    Energy-efficient cookstoves, **477**
    Landsat stations, **764**
Uranium mill tailings, 145, 153
Uranium resources, 365, 367, 743, 744
Urban areas
    Growth, **14, 15, 23, 325, 505–506, 508**
    Pesticides, **771, 772**
    Pollutant runoff, **131, 772**
    Transportation, **338, 340, 341, 476, 778**
    Wastes, **748–749**
US . . . (organizations)
    See other part of name
US/Israel Binational Foundation for Industrial Research and Development, 483, 485
US/Mexico Agreement on Arid Lands Management and Desertification Control, 763, 803
US Steel, 337
US/USSR Maritime Agreement of 1972, 335
USSR
    Agricultural production, **497, 499, 788**
    Cognitive science research, **91**
    Demographic features, **7, 9, 12, 19, 20, 505**
    Earthquake prediction, **764**
    Energy development, **303**
    Energy resources, **311, 739, 741**
    Information control, **469**
    Magnetohydrodynamics facility, **358**
    Maritime agreement, **335**
    Military threat, **469, 471, 526, 704, 706**
    Mineral resources, **518, 520**
    Polymer science education, **205**
    R&D expenditures/growth, **xx, 409, 704**
    Radioactive waste management, **147**
    Scholarly exchange program, **551**
    Sci/tech education, **796**
    Seabed mining, **765**
    Space/satellite programs, **177, 719, 720, 722, 807**
    U.S. embargo toward, **468, 471, 494, 526**
    U.S. mineral imports from, **364, 366**
Utah
    Green River oil shale, **319, 329**

V

Venus, 160, 755
Veterans Administration (VA), 731, 732, 734
Video devices, 410, 411–413, 792–793, 794
Viking missions, 722
Virginia
    Hampton Roads port facility, **337**
    Hopewell Kepone poisoning, **731**
    Virginia Beach water desalting plant site, **763**
Viruses, 38–39, 117, 119, 129, 352, 730
Voyager missions, 722, 755

W

Wampler, Congressman William, 452
Warsaw Pact, 710
Washington DC
    Blue Plains wastewater treatment plant, **136**
Washington (State)
    Hanford nuclear waste plant, **145, 147, 151**
    Lake Washington, **99, 133**
    Mt. St. Helens, **162, 764**
    Seattle port facility, **336**
Waste management, 128–130, 131, 136, 291, 299, 748–749, 768, 805
    See also Nuclear waste management
    See also Wastewater management
Wastewater management, 131, 135, 326, 749, 772
Water and Power Resources Service, 135
Water pollution, 123, 125–138, 723, 766, 772, 805
    Agriculture, **130–131**
    Energy, **326**
    Radioactive wastes, **152**
    Transportation, **345**
Water Research and Development Act of 1978, 763
Water Research and Technology, Office of (OWRT), 763
Water Resources Council, 124
Water supply, xxviii, 123, 124–125, 763, 802–803
    Agricultural use, **21, 125, 783**
    Conservation, **135–136**
    Ecology, **99–100**
    Energy use, **125, 326**
    Global concerns, **800, 802–803**
    See also Drinking water
Wave energy, 303, 804
Weapons systems
    New, **710–711**
    Theory, **469–470, 525, 527, 529–530**
Weather
    See Climate and weather
Weight control
    See Obesity
West Germany
    See Germany, Federal Republic of
West Valley Demo Project, 744
Western Europe
    See Europe
Westinghouse, 357, 358
White Sands Missile Range, 710
Wind energy, 749
Wisconsin
    Sanguine test facility, **180**
    Social stratification study, **630**
Women
    Cigarette smoking, **656–657**
    Employment, **687–688, 796**
    Occupational health, **455**
    See also Reproduction, human
    See also Sex differences
Wood (energy source), 309, 310, 322–323
    See also Biomass
    See also Forest resources
Worcester Institute, 278
Word processing, 90, 422, 427, 794
Work force
    See Employment
World Administrative Radio Conference, 426, 724
World Bank, 801
World Climate Program, 803
World Food Council, 801
World Food Program, 801
World Health Organization, 486, 806
World Meteorological Organization, 486, 803
Wyoming
    Green River oil shale, **319, 329**

Y

Yugoslavia
    Demographic features, **9**

Z

Zaire
    Cobalt resources, **517–518**
    U.S. mineral imports from, 364
Zambia
    Copper resources, **518**
Zenith, 414, 415
Zinc resources, 17, 364, 366, 519

Page numbers i–385 are in the first *Source Volume;* page numbers 387–807 are in the second *Source Volume.*

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